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Sustainability of Traditional Paddy Rice Processing Techniques Among Smallholder Rice Farmers in Southeast Nigeria

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Abstract

Rice is a major staple food consumed worldwide, but its processing has significant environmental impacts due to water and energy consumption and greenhouse gas emissions. As a result, rice producers are adopting sustainable processing techniques to reduce negative environmental impacts and increase profitability. This study analyzed the sustainability of modern and traditional paddy rice processing techniques among smallholder rice farmers in Southeast Nigeria. The data was collected from 240 rice producers using statistical approaches such as descriptive statistics, sustainability indicator (Weight Assessment Ratio Analysis), and multinomial regression analysis. The results showed that 34.7% of rice farmers used modern processing techniques while 65.3% used traditional methods. Traditional milling produced substantial carbon emissions, according to 77% of small-scale farmers, while 68% rated noise pollution as high. 80-100% of small-scale farmers using modern techniques cared about the environment and wanted to reduce their gas emissions, solid waste, energy use, and water use. The sustainability index for farmers using traditional and modern processing techniques was affected by gender experience, labor size, investment, income, cost of production, understanding of climate change, and environmental sustainability. The study recommends using renewable energy sources to increase productivity and reduce environmental effects.

Keywords: Emissions, Energy consumption, Environmental impacts, Investment, Productivity, Profitability

Introduction

Rice is a staple food for millions of Nigerians and plays a crucial role in food security across West Africa (Akinbile, Ogunmola, Abolude, & Akande, 2020; Soullier, Demont, Arouna, Lançon, & Del Villar, 2020). Rice consumption in Nigeria is projected to rise by 4% to 7.8 MMT in MY (Million Metric Tons in Marketing Year) 2023/24, marking an increase in consumption compared to other African staples like wheat and corn (United United States Department of Agriculture Foreign Agricultural Service, 2023).Smallholder farmers are the primary producers of rice in Nigeria (Esiobu, Onubuogu, Njoku, & Nwachukwu, 2020; Onyeneke, Amadi, Njoku, & Osuji, 2021), and the government has implemented policies to boost local production and reduce imports (Ikebudu, 2021; Karkare, Odijie, Ukaoha, & van Seters, 2022).

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involve complex procedures requiring various technologies (Sethy, Barpanda, Rath, & Behera, 2020). While large-scale operations utilize highly-mechanized processes (Materne & Reddy, 2007), most smallholder farmers in Nigeria still rely on traditional, labor-intensive methods (Bello, Baiyegunhi, & Danso-Abbeam, 2021; Obianefo *et al.*, 2021). These traditional techniques, though less efficient, are perceived to preserve food quality and nutrition better than modern methods (Adekoyeni, Fagbemi, & Ismaila, 2018; Danbaba *et al.*, 2019; Zhao, Lin, & Chen, 2020).

However, the increasing costs of labor and resources are pushing more smallholder farmers towards adopting more efficient rice production methods to remain competitive (Akite, Okello, Kasharu, & Mugonola, 2022; Bello *et al.*, 2021; Obianefo *et al.*, 2021). This shift presents opportunities for the sustainable development of Nigeria's small-scale modern rice processing industry (Kosemani & Bamgboye, 2020; Onyekwena, 2016; Salisu, Gao, & Quan, 2021).

Both traditional and modern rice processing techniques have environmental implications, including carbon emissions, solid waste generation, water pollution, and noise pollution (Chungsangunsit, Gheewala, & Patumsawad, 2005; Kumar, Priyadarshinee, Roy, Dasgupta, & Mandal, 2016; Lenis Rodas, Morales Rojas, Jaramillo Marín, Salcedo Jiménez, & Pérez Bayer, 2022; Lim, Manan, Hashim, & Alwi, 2013). The sustainability of these processes must be evaluated considering environmental, economic, and organizational factors (Batista & Francisco, 2018; Dzhengiz, 2020; Gowda & Jayaramaiah, 1998; Roy, Chan, & Xenarios, 2016).

While previous studies have examined various aspects of rice processing techniques, there are several gaps in the existing literature. First, there is limited research specifically focusing on the sustainability of traditional paddy rice processing among smallholder farmers in Southeast Nigeria. Second, many studies have focused on either environmental or economic aspects, but few have integrated all three dimensions of sustainability (environmental, economic, and organizational) in their analysis. Third, while some researchers have used econometric models to study the effects of various factors on sustainability (De La Maza, Davis, & Azevedo, 2021; Rajabov & Mustafakulov, 2020), there is a lack of comprehensive studies applying both Multinomial Logistic Regression and Weight Assessment Ratio Analysis (WARA) to assess the sustainability of rice processing techniques. Lastly, the existing literature often fails to provide a clear comparison between traditional and modern processing techniques in terms of their overall sustainability within the context of smallholder farming in Nigeria.

Given these gaps, the objectives of this study are:

1. To examine the distribution of modern and traditional rice processing techniques among smallholder farmers in Southeast Nigeria.
2. To assess the environmental effects of both traditional and modern rice processing methods in the study area.
3. To evaluate the sustainability of traditional paddy rice processing techniques using a comprehensive approach that integrates environmental, economic, and organizational factors.
4. To identify the key determinants influencing the adoption and sustainability of different rice processing techniques among smallholder farmers.
5. To provide evidence-based recommendations for policymakers and stakeholders to promote sustainable rice processing practices in Nigeria.

Materials and Methods

The study was carried out at three locations: Abia, Ebonyi, and Imo states in southeastern Nigeria. These states are predominantly agrarian and major producers of paddy rice (see Figure 1). A two-stage sampling technique was used to select the rice processors. The first stage was the purposive selection of the state's rice-producing communities. The second stage was randomly selecting 240 rice farmers from the selected communities. The researchers visited each farm periodically to collect data about the sustainability performance of the modern and traditional paddy processing systems. Data were collected using a survey and focused group discussion. The data collected were analyzed using statistical tools such as descriptives, sustainability index (Weight Assessment Ratio Analysis), and multinomial regression analysis. The farmers' perception of organizational sustainability was characterized by conducting a content analysis of the transcripts of their responses (Baccar, Bouaziz, Dugué, Gafsi, & Le Gal, 2020). To estimate the factors affecting the sustainability index of traditional rice milling, the following multinomial logit model was adopted.

$$Pij = \frac{e\, B_j X_i}{1+\sum_{k=0}^{j} X^B k X_i} \quad \ldots \qquad (1)$$

The explicit form of the model is stated as:

$$\log\left(\frac{pij(categoryi)}{Pij(categoryref)}\right) = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8 + b_9X_9 + b_{10}X_{10} + e_i \qquad (2)$$

where:
P= probability
i = 1, 2, 3, ..., n variables
j= categories
Y= high=1, average =2, and Y*ref*= low =5
X_1= level of education of the small-scale farmers, measured in years
X_2=sex (male=1 and female=0)
X_3 = experience of the small-scale farmers,measured in years
X_4 =labor size of traditional rice mills,measured in numbers
X_5 =investment of traditional rice mills in naira
X_6 =income of traditional rice mills in naira
X_7 = cost of production of traditional rice mills in naira
X_8=knowledge of climate change of small-scale farmers using traditional rice mills (yes =1, no=0)
X_9 =knowledge of economic sustainability of small-scale farmers using traditional rice mills (yes =1, no=0)
X_{10}=knowledge of organizational sustainability of small-scale farmers using traditional rice mills (yes =1, no=0)
b_i = the parameter
e_i = the error term

To estimate the factors affecting the sustainability index of modern rice milling, the following multinomial logit model was adopted

$$Pij = \frac{e\, B_j X_i}{1+\sum_{k=0}^{j} X^B k X_i} \qquad (3)$$

The explicit form of the model is stated as

$$\log\left(\frac{pij(categoryi)}{Pij(categoryref)}\right) = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8 + b_9X_9 + b_{10}X_{10} + e_i \qquad (4)$$

where:
P= probability
i = 1, 2, 3, ..., n variables
j= categories
Y= high=1, average =2, and Y*ref*= low =5
X_1= level of education of the small-scale farmers, measured in years
X_2=sex (male=1 and female=0)
X_3= experience of the small-scale farmers using modern mills,measured in years
X_4= labor size of modern rice mills, measured in numbers
X_5= investment of modern rice mills in naira
X_6= income of modern rice mills in naira
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X_{10}= knowledge of organizational sustainability of small-scale farmers using modern rice mills (yes =1, no=0)
b_i = the parameter
e_i = the error term

The Weight Assessment Ratio Analysis (WARA) model (Dehnavi, Aghdam, Pradhan, & Varzandeh, 2015; Ghenai, Albawab, & Bettayeb, 2020; Zavadskas, Stević, Tanackov,

& Prentkovskis, 2018) is specified as follows:

$$W_j = \frac{q_i}{\sum_{k=1}^{m} q_k} \quad (5)$$

where:

W_j = relative weight criteria of the farmer's response to sustainability questions

i = individual farmer response

j = 1, 2, …, n

q = the rank of the farmer response

m= sample size

Endogenous variables: Information was gathered through questionnaires and interviews with the rice farmers. The data collected is based on the processing activities of rice farmers. The data collected on environmental sustainability was computed using the Weight Assessment Ratio Analysis (see equation 5) to get an index score to measure the environmental impact of rice processing using modern and traditional methods. The high index score is 0.7-1, the average is 0.5-0.69, while the low index is <0.5 (Daniel, Tsoulfas, Pappis, & Rachaniotis, 2004). This indicates the adverse impact of processing rice on the farmer and the environment. The index is the dependent variable for the multinomial logit models (see equations 2 and 4) performed in this study.

Exogenous variables: The exogenous variable is the independent variable included in equations 2 and 4, which influences the environmental sustainability of traditional and modern rice processing, respectively. The first variable is the level of education of the farmers. Some reports on environmental sustainability considered education as a factor (Anabaraonye, Okafor, & Hope, 2018; Baur, 2022; Jayne, Snapp, Place, & Sitko, 2019; Mancini, Termorshuizen, Jiggins, & van Bruggen, 2008). The sex of the farmers was considered as another variable. Gender, the roles assigned to different sexes that vary across societies and cultures, is an essential component of any sustainability study involving farmers (Aluko, 2018; Jellason, Conway, & Baines, 2021). The experience of the farmers in rice processing and their knowledge of the traditional and modern methods of rice processing were also considered important variables for the study (Ojo & Baiyegunhi, 2020a; Ojo, Baiyegunhi, Adetoro, & Ogundeji, 2021). Moreover, labor size, a measure of the number of workers used to process the paddy, has been included as an important variable as it affects the total time spent on processing the paddy (Kulyakwave, Xu, Yu, & Mwakyusa, 2022; Mujeyi, Mudhara, & Mutenje, 2021). Amount of investment in the processing as an exogenous variable was also considered because the amount of investment in the equipment used in the processing of paddy affects the processing time, which in turn affects the environmental impact of the entire process (Salisu, Gao, & Quan, 2021). Lastly, the cost of production and income are important as they affect the ability of the farmer to purchase inputs needed in the processing of paddy, affecting the processing time and the environment of the process (Onyeneke, 2021).

Results and Discussion

Distribution of rice processing methods among farmers

The distribution of the farmers according to their use of the traditional or modern method of rice processing is presented in Table 1. The table showed that 34.7% of rice farmers use modern rice processing methods, while 65.3% use the traditional method of rice processing. The percentage split showed that the two rice processing methods are popular with rice farmers in Nigeria. However, the data reveals that the percentage of farmers employing traditional rice processing methods in the region is nearly double that of those utilizing modern techniques. The higher number of traditional processing techniques can be associated with the cost of purchase and maintenance of modern processing equipment. Additionally, there is this perception among local processors that the traditional processing of paddy rice is more efficient and reliable than modern rice processing methods (Anthony, Alabi, Ebukiba, & Gamba, 2021; Sissoko, Ohene-Yankyera, & Wongnaa, 2021; Tahir, Onewo, & Alkali, 2022). However, according to Hasan, Tanaka, Alam, Ali, and Saha (2020) and Soullier *et al.* (2020), this method results in lower throughput capacity compared to farmers who use modern machinery to process their rice. The results agreed with the finding of Yusuf (2018) that rice farmers in Nigeria use more traditional rice processing methods, which have resulted in a low level of processing output and quality of rice produced. This low yield is probably due to the daily drudgery with manual labor involving traditional techniques.

Table 1- Methods of paddy rice processing

Technique of paddy rice processing	Frequency	Percentage
Modern processing	83	34.72803
Traditional processing	156	65.27197
Total	239	100

Effect of processing techniques on riceyield and quality among farmers

The investigation strongly suggested that land availability determines the quantity of rice grown and the amount of rice processed. First, however, we categorize the rice farmers based on the quantity of rice processed (see Figure 2). From the questionnaire, we grouped the processors into three: those that process 0.5 to 5 tonnes of rice daily, 6 to 10 tonnes daily, and 11 to 15 tonnes daily. Then, each group was separated based on those that used modern processing techniques and those that used traditional techniques. Figure1 shows the quantity of rice produced using traditional and modern processing techniques for each category. According to the graph, in the 0 to 5 tonnes category, about 77% of rice farmers use traditional milling methods, while 8% use modern milling methods. In the6 to 10 tonnes daily category, 58% of processed rice was by modern milling methods, while 20% used traditional milling methods. Furthermore, in the11 to 15 tonnes daily category, 34% used modern milling methods, while 3% used traditional methods. The analysis revealed that the use of milling methods is correlated with the amount of rice produced. However, Figure 2 shows that processors are dominated by rice millers in the category of 0.5 to 5 tonnes daily. The reason is that the farming cluster is dominated by small farm holders whose first objective is to feed their families before selling the excess. This finding agreed with Kyaw, Ahn, & Lee (2018), who asserted that small-scale rice farmers typically mill less rice than is necessary to provide their families with sufficient income. Low-quantity rice milling can result from acombination of available quantity to mill, effective milling systems, and drudgery due to local milling techniques. However, Ndirangu & Oyange (2019) noted that the modern milling procedure could increase rice farmers' daily output from 1.5 to 3 tonnes. This increase in output is because of the availability of high-capacity modern mill machines and efficient material handling techniques, which enable rice farming to be more productive and profitable for small-scale farmers. However, the trend observed among most rice farmers in most Sub-Saharan countries is the continued use of traditional milling methods due to the limited access to reliable and affordable machines (Fatunbi & Kombat, 2020).

The information regarding these quality indices was provided by farmers and processors who were asked to rate the degree of acceptability on a scale of 0 to 5, with 0 being the lowest and 5 being the highest (refer to Figure 2). The participants willingly shared their insights to contribute to the research and provide valuable data on the perceived quality of rice produced using different processing methods. Concerning palatability, the average response from small-scale farmers using traditional milling techniques was 3.5, while those using modern milling techniques rated it at 3. This indicates that the traditionally milled rice was perceived to have better palatability among the respondents. The farmers' input on this aspect helps in understanding the preference for rice processed through traditional methods. However, it is important to note that the nutritional content of traditional and milled rice was not the focus of this research and falls beyond its scope. This acknowledgment is necessary to avoid drawing conclusions regarding the nutritional differences between the two processing methods.

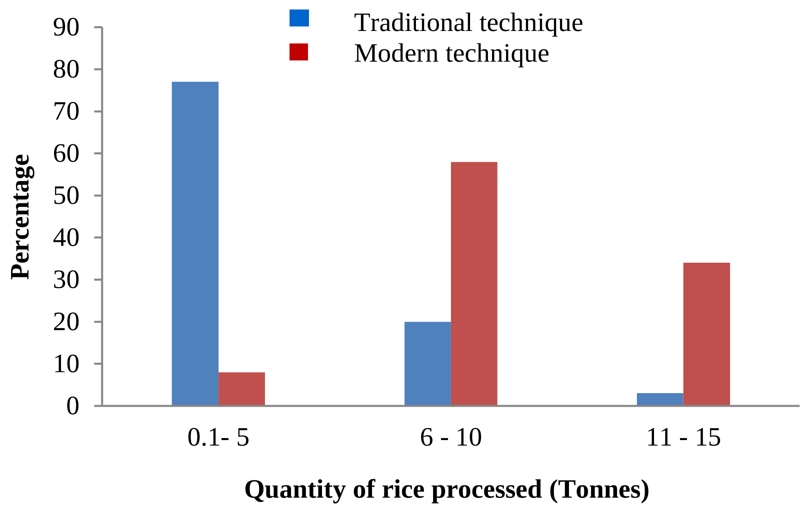

Fig.1. Quantity of rice produced using the traditional and modern method

Moving on to the assessment of appearance, a comparison between small-scale farmers using traditional milling techniques and those using modern mills revealed notable differences. Traditionally milled rice received a low rating with a mean response of 1.5, while modern milled rice scored significantly higher at 3.7. This difference in ratings can be attributed to the fact that traditionally milled rice retains more of the bran layer of the paddy kernel, as supported by previous studies (Dhankhar & Hissar, 2014; Tong, Gao, Luo, Liu, & Bao, 2019). The farmers and processors' input on appearance offers valuable insights into the visual appeal of rice processed using different methods.

In terms of taste, the respondents rated traditionally milled rice equal to modern rice mills. This implies that there was no significant difference in taste perception between the two processing methods. The input provided by the farmers and processors aids in understanding the taste-related aspects of rice quality and helps in evaluating the potential consumer preferences.

Considering cooking time, the farmers rated traditionally milled rice as having a faster cooking time, with a mean rating of 3.8, while modern milled rice received a slightly lower rating of 3.5 (refer to Figure 2). This information contributes to the understanding of the practical aspects of rice preparation and may influence consumer choices based on convenience and time-saving factors.

Access to available modern rice processing machines

The cluster of rice processing machines available from the respondents was a dehusking, pre-cleaning machine, aspiration or winnowing machine, destoner, paddy separator, weighing machine, sifter, grader, polisher, blender, and bagging/packaging machines. Farmers were questioned about access to each machine in the three study areas. The distribution of the respondents is shown in Figure 3. From the Figure, about 14% and 15% of the rice farmers had access to pre-cleaning and paddy separator machines, respectively. Dehusking, de-stoning, packaging, and weighing machines were accessed by 10%, 12%, 13%, and 15% of the rice farmers, respectively (see Figure 4). The farmers who use length grading, husk aspiration, and polishing machines were 5% each, while 2% and 4% of the rice farmers have access to sifting and blending machines, respectively. There was a clear trend in which small-scale farmers with fewer machines have smaller farms with lower productivity. However, most farmers in the study areas had poor access to machinery. It has been reported that farmers with access to the highest numbers of machines also produced the most rice per hectare (Bello *et al.*, 2021; Panpluem, Mustafa, Huang, Wang, & Yin, 2019). This finding suggests that having access to multiple machines is crucial as it increases farm productivity and allows farmers to diversify their income streams. Moreover, it was observed that despite the few machines available to most farmers, they could produce a significant amount of rice and sell their products at a value higher than the market price and therefore earned higher incomes than imported rice. Thus, this positive correlation between the number of machines and average output can be achieved only when the farmers can use these machines effectively to carry out the desired tasks (Osabuohien, Okorie, & Osabohien, 2018). Therefore, these results suggest considerable room for improvement regarding farmer knowledge and proficiency with the various types of machines available in the study area.

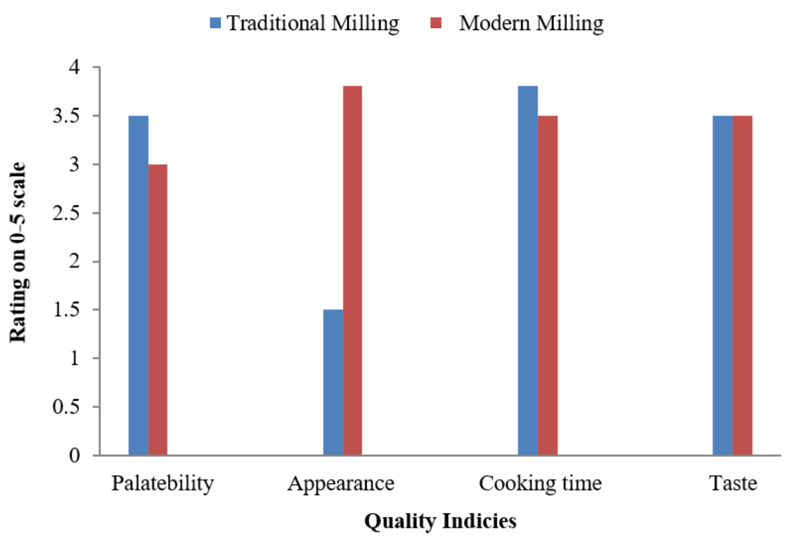

Fig.2. Quality of rice produced using the traditional and modern method

Environmental effects of rice processing

Modern rice processing can significantly impact the environment, particularly when inefficient machines and systems are used, resulting in a range of negative environmental consequences. These attributes were noise pollution, carbon emission due to fossil fuel use, wastewater discharge to the environment, high water usage, and high solid waste used to large amounts of processed rice. Farmers were asked how these indices affect them and the community where the processing machines are located. They were asked to rate these attributes in terms of low, moderate, and high among them and the community. Figure 4 shows that 68% of the respondents identified noise pollution as a primary concern, while 42% identified carbon emissions from the machines as a primary concern. Water usage and water pollution were of minor concern, while solid waste discharge was third in the least of their environmental concerns. The reason is that modern rice processing methods contribute minimally to water use, water pollution, and solid waste. When weighted as a single factor of environmental effects, the overall view indicated that about 31%, 30%, and 39% of rice farmers rate the environmental effects of modern rice processing to be high, moderate, and low, respectively. It has been reported that rice mills operating with a single-cylinder engine and flat belt drives produce more noise than those being run using an electric motor along with flat belt drives, and the single-cylinder engine rice millers are more prevalent in sub-Saharan Africa (Nag & Gite, 2020; Oyedepo, 2019).

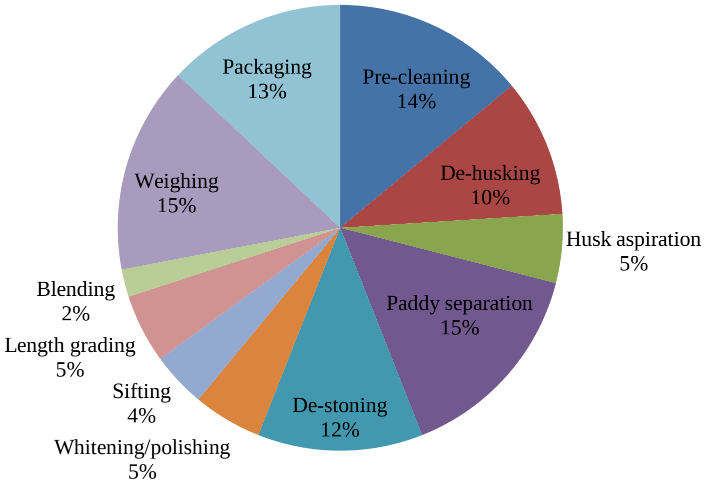

Fig.3. Machines used for modern processed rice

Furthermore, the commonly observed causes of high noise in the rice mills may be due to the use of a long flat belt drive, crank-and-pitman mechanism, absence of an electric motor enclosure, poor machine maintenance, and inadequate acoustic design of the workroom in the rice mill (Paudel & Baral, 2020). Studies have shown that excessive noise exposure can adversely affect human health, including hearing loss and other chronic health conditions (Mansor *et al.*, 2020; Seidman & Standring, 2010). Also, ithas been reported that modern mills emit low carbon compared to traditional mills, which are operated by direct combustion of rice straws and residues (pellets) (Field, Tanger, Shackley, & Haefele, 2016; Wassmann *et al.*, 2021). The water used by a modern rice mill is primarily forcleaning rice; therefore, the overall water usage is generally minimal. However, water used for cleaning purposes in rice mills may carry high levels of phosphorus, nitrogen, and organic matter (Sayanthan & Thusyanthy, 2018). Wastewater from rice mills also contains high levels of inorganic and organic contaminants, posing a hazard to the environment (Kumar & Deswal, 2021). Several chemical constituents present in the effluents from rice mills pose a potential threat to humans if present in high enough concentrations. In 2011, researchers in Thailand reported that rice grains might generate hazardous gases, which can replace oxygen (O_2) in confined spaces (Parnphumeesup & Kerr, 2011; Resanond, Jittsanguan, & Sriphraram, 2011). These gases may contribute to explosions and other severe accidents and adversely affect human health and the environment.

The traditional rice processing method has some environmental effects, too, as observed by the respondents. Using the same rating method in Figure 4 above, Figure 5 showed that about 76% of the respondents indicated that the level of carbon emission from the traditional milling method is high. In comparison, 67% of the farmers identified water use and water pollution as of significant concern. However, only 58% indicated that solid discharge is of significant concern, while 52% mentioned noise pollution as a concern in traditional rice processing. When compared to the overall weighted average of the environmental effect of the modern methods, the overall environmental effect of the traditional method was 11% higher than the modern methods of rice processing among the respondents. It has been noted that waste generated during the milling process for most traditional millers ends up in streams or rivers. At the same time, some of the wastewater from the mills is releasedinto the environment without proper treatment (Rasheed *et al.*, 2020). Using outdated milling machines also leads to higher particulate matter emissions and greenhouse gases, such as methane and carbon dioxide (Motevali, Hashemi, & Tabatabaeekoloor, 2019).

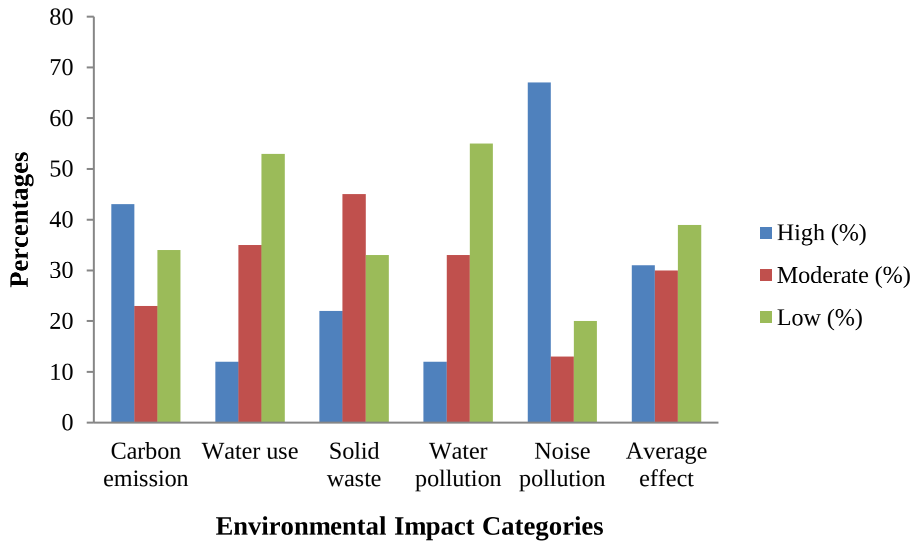

Fig.4. Environmental effects of modern processed rice

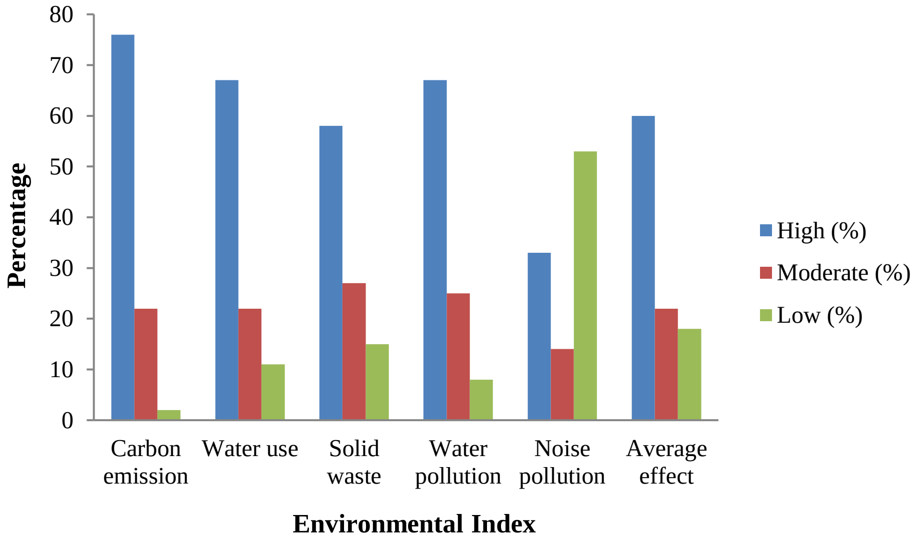

Fig. 5. Environmental effects of traditional rice processing technique

Farmers have reported that wastewater from their rice milling activities can reach the watercourses, thereby polluting the water sources and affecting the local people's health

(Akiwumi, 2019; Njoku, Nwali, & Ajana, 2017). Solid waste is a significant concern among rice farmers,as it is frequently dumped into the soil without proper treatment, resulting in soil degradation and loss of fertility (Nwachukwu, Ikeagwuani, & Adeboje, 2021; Ulakpaa & Eyankwareb, 2021).

This finding shows that farmers need to incorporate more sustainable practices into their operations by switching to eco-friendly and sustainable practices. Consequently, there is a decline in traditional mill operations, leading to the acquisition of more efficient and quieter equipment. Additionally, enhanced water management practices and reduced carbon emissions are achieved through better waste management. Farmers, therefore, should be open to learning new practices that could improve their agricultural operations and find ways to lower the cost and risk involved in implementing these new sustainable practices in their business operations, such as the utilization of improved equipment and machinery, allowing them to increase productivity while reducing their production costs and negative environmental impact (Vogel *et al.*, 2020).

The sustainability index of the traditional and modern rice milling methods

The sustainability index in wireframe contour plots (Figure 6), following the index computed by applying equation 5, shows that small-scale farmers using the traditional rice milling method care about the environment, with 80-100 percent willing to reduce their gas emissions, solid waste, energy use, and water use. At the same time, profit increases, an aspect of business sustainability.

From Figure 6, the average sustainability score of the rice farmers is 60 percent, which shows a moderate level of concern for the UN Sustainable Development Goals (Acosta, Maharjan, Peyriere, & Mamiit, 2020; Gil *et al.*, 2019). This finding shows that they need to improve their business and organizational sustainability and incorporate more sustainable practices into their operations. By reducing the number of traditional mill processes, investing in more efficient equipment, improving water management, reducing carbon emissions through better management of their waste, switching to eco-friendly and sustainable practices, and investing more time and planning on how to lower the cost of production. Collaborate with local environmental agencies to improve farm pollution management while maintaining good profit margins, and partner with other small-scale farmers. Moreover, a similar business model can help build a strong community that supports each other's ventures (Donner, Verniquet, Broeze, Kayser, & De Vries, 2021; Inman *et al.*, 2018; Sarkis, Cohen, Dewick, & Schröder, 2020; Zucchella & Previtali, 2019). To improve their overall sustainability score, small-scale farmers should be open to learning new practices that could improve their agricultural operations and find ways to lower the cost and risk involved in implementing these practices in their business operations, such as the utilization of improved equipment and machinery that would allow them to increase productivity while reducing their production costs and the reliance on manual labor and emissions (Vogel *et al.*, 2020).

The sustainability index in wireframe contour plots (Figure 7), derived by applying equation 5, shows that small-scale farmers use the modern method of rice milling. The small-scale farmers have a percentage of 80-100 focusing on environmental sustainability indicators such as energy and water use. Their organizational and business sustainability index indicates a high percentage for profit, investment, cost management, and long-term planning. The concern for carbon emission and solid waste was 20-40 percent. Their sustainability index focuses on environmental sustainability indicators, such as energy and water use. The sustainability index of the small-scale farmers using the modern method of rice milling shows a percentage above 80. According to researchers, modern rice processing is more economically and environmentally sustainable than manual rice processing (Devkota *et al.*, 2020; Kosemani & Bamgboye, 2020).

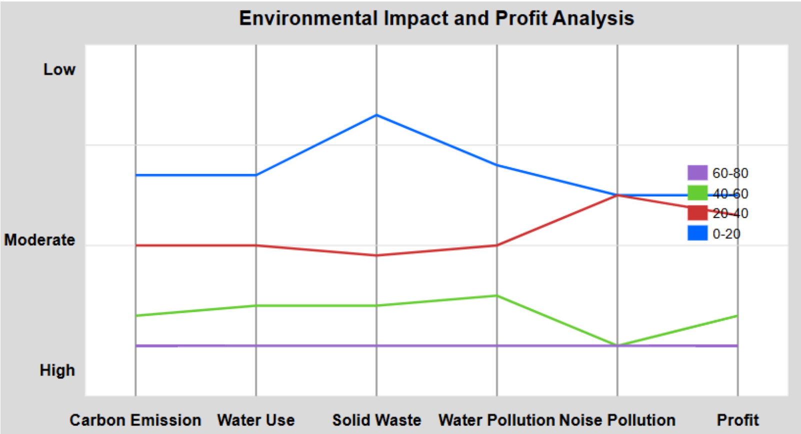

Fig. 6. Wireframe contour plots of the sustainability index of traditional processing technique

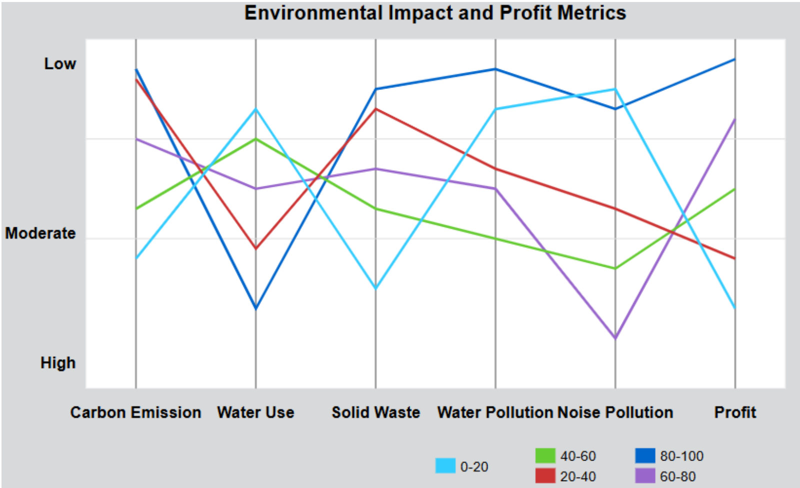

Fig.7. Wireframe contour plots of the sustainability index of modern processing technique

Factors affecting the sustainability index of paddy rice processing

Applying equations 1 and 2, the observed variables that might have an impact on the long-term viability of paddy rice processing are shown in Table 2. The distribution shows that the model's chi-square probability (124.93) was statistically significant at 1%. The independent variables that were included in the model had significant effects, leading to the rejection of the null hypothesis. So, we agree with the alternative theory that the independent factors that were included had a big impact on the dependent variable. The strength of the model is indicated by the Cox and Snell, McFadden, and Nagelkerkepseudo R-square values, which are 0.75, 0.853, and 0.656, respectively. This indicates that the collection of variables included in the model accounts for between 75.0, 85.3, and 65.6 percent of the variability. The model is 98 percent accurate, according to the proportionate by chance accuracy rate (Bayaga, 2010). The likelihood ratio test evaluates the overall relationship between the dependent and independent variables (Bayaga, 2010).

The gender (sex) of the small-scale farmers using the traditional rice mills was statistically significant at 1% and positively related to the level of sustainability. Gender has long been recognized as an essential factor in the production process of small-scale rice farmers in developing regions, where each gender has unique roles and responsibilities. These gender roles create significant advantages and disadvantages for female small-scale farmers of rice-growing communities in their understanding and choice of sustainability practices. The heavy responsibilities placed on women contribute to the low participation rate of women in agriculture, making them less likely to adopt environmentally sustainable practices such as composting, not using chemicals, and planning the rice mill business. However, women tend to have a better understanding of household issues and are more likely to educate their children about environmental issues; they can be the driving force behind the adoption of sustainability practices and play a vital role in advancing environmental sustainability in their communities.

The traditional rice milling experience of the small-scale farmers was statistically significant at the 1% and positively related to the level of sustainability (see Table 2). The correlation between sustainable rice production and small-scale farmers' experience in the rice mills' production management is significant (Bello *et al.*, 2021). The experience of the rice producers in milling their rice at the mill is significant in the rice farming process because this is a critical process that contributes to the quality of rice and the sustainability of the process and environment. Improving small-scale farmers' experience and skill level in milling rice will create a better environment for sustainable rice production. Improved experience will make the production process more sustainable for farmers and improve the quality of the produced rice.

The labor size of the small-scale farmers using traditional rice mills was statistically significant at the 1% and positively related to the level of sustainability, as presented in Table 2. This finding is because, as the labor size increased, the efficiency in using energy in small-scale farms also increased (Stępień *et al.*, 2021). As a result, small-scale farmers could harvest more paddy from the land and process them, increasing rice production. In contrast, when the labor size decreased, the efficiency of the small-scale farmers in terms of energy consumption also fell, causing a drop in the sustainable production of rice. This finding can be attributed to the fact that farmers who use smaller quantities of laborers cannot achieve maximum efficiency of inputs in their operations, which affects the sustainability of their production (Dahlin & Rusinamhodzi, 2019; Houedjofonon *et al.*, 2020). However, the labor size of small-scale rice farmers using traditional mills also affects environmental sustainability. This finding is because the energy and manpower-intensive nature of the traditional rice milling processes means that the farmers will consume a small amount of non-renewable energy sources and high raw materials such as land and water. Non-renewable energy is the leading cause of climate change, and reducing the quantity used will improve environmental sustainability (Khan, Trinh, Khan, & Ullah, 2022). However, these resources are limited and cannot be replenished by natural means. Therefore, it is vital to use these resources responsibly to preserve the environment for future generations.

The investment of the small-scale farmers using traditional rice mills was statistically significant at the 1% and positively related to the level of sustainability, as shown in Table 2. This finding implies that the investment the small-scale farmers make increases the sustainability of the farmers using traditional rice mills. Based on the findings of Ritthaisong, Johri, and Speece (2014), investment in the mills results in the economic sustainability of the rice milling business. Jirapornvaree, Suppadit, and Kumar (2021), reported on the impacts of the sustainable production of jasmine rice. They concluded that the investment in modern rice mills positively impacts the environmental and economic sustainability of rice farming enterprises in Indonesia. The income of the small-scale farmers using traditional rice mills was statistically significant at 10% and negatively related to the level of sustainability, as presented in Table 2. This result implies that the income of small-scale farmers negatively affects their sustainability practices. Some reports are similar to our findings that income affects sustainability practices adversely (Ndayambaje *et al.*, 2019;

Olanipekun, Olasehinde-Williams, & Alao, 2019; Ojo & Baiyegunhi, 2020b). A study by Qadir *et al.* (2014) found in their research that as the income of farmers increased, the adoption of sustainable land management practices decreased. The study also found a negative relationship between household income and sustainability. Several reasons may explain this relationship between income and sustainability. Krishnankutty, Blakeney, Raju, and Siddique (2021) found similar results to our study, where lower-income farmers were less proactive in their agricultural management processes. In our study, we hypothesized that as the level of income increases for farmers, they would adopt more sustainable agricultural practices. However, Krishnankutty *et al.* found that this was not the case; instead, as income levels increased, sustainable practices decreased.

The cost of production was statistically high at 1% and negatively related to the level of sustainability. This result implies that the production cost impedes small-scale farmers' ability to adopt sustainability practices. Some researchers reported that higher production costs resulted in a lower adoption of sustainable practices by small-scale farmers in developing countries (Samson *et al.*, 2018). This finding is primarily due to the higher input costs required to implement and maintain sustainable agriculture and processing systems by rice farmers compared to conventional agriculture systems. In addition, most smallholder farmers are low-income earners who find investing in costly sustainable practices that improve socioeconomic well-being challenging. Thus, the long-term impact of adopting cost-reducing and sustainable practices on agricultural production is hard to predict due to the short-term costs associated with adopting such practices by rice farmers. Nonetheless, the long-term economic benefits of farmers' large-scale adoption of sustainable farming practices and food processing technologies would be significantly higher as it would contribute towards reducing the dependence on expensive chemicals.

Table 2- Factors affecting the sustainability index of the traditional rice processing technique (Equation 2)

Power of classification of the sustainability index of the traditional milling process				
	High	**Moderate**	**Low**	**Percent correct**
High	43	8	14	100
Moderate	23	15	10	95
Low	16	7	15	96
Overall percentage	53	20	25	98
Effect	**Model Fitting Criteria**	**Likelihood Ratio Tests**		
	-2 Log Likelihood of Reduced Model	**Chi-Square**	**p-value**	
Intercept	67.896	2.251	0.025	
Education level	22.134	0.612	0.462	
Sex	70.775	5.131	0.001	
Experience	72.717	7.073	0.000	
Labor size	84.561	9.3321	0.000	
Investment	72.214	6.57	0.002	
Income	-67.536	-1.892	0.043	
Cost of production	-73.921	-8.277	0.000	
Knowledge of climate change	22.032	1.235	0.881	
Perception of economic sustainability	58.036	3.021	0.021	
Perception of business sustainability	66.547	2.418	0.075	
Cox and Snell	**Nagelkerke**	**McFadden**		
0.75	0.853	0.656		
Chi-square	124.93			

The perception of sustainability was statistically significant at 10% and positively related to the level of sustainability. This result implies that the small-scale rice farmers' perception of economic sustainability promotes the ability of the small-scale farmers to adopt sustainability practices.

Equations 3 and 4 were used to obtain the result in Table 3. The distribution shows that the model's chi-square probability (89.254) was statistically significant at 1%. Therefore, the independent variables included in the model were significant effects, and the null hypothesis was rejected. So, we agree with the alternative theory that the independent variables that were included have a significant impact on the dependent variable. The model's strength is indicated by the pseudo R-square values of Cox and Snell, McFadden, and Nagelkerke, which are 0.65, 0.78, and 0.55, respectively. It indicates that the set of variables used in the model accounts for between 65.0, 78, and 55 percent of the variability. Therefore, the model is 98 percent accurate, according to the proportional by chance accuracy rate (Bayaga, 2010).

The level of education of the small-scale farmers using modern rice processing was statistically significant at 1% and positively related to the level of sustainability, as shown in Table 3. This result implies that the skills and training acquired, especially through collaboration with aid extension agents and information communication technologies by small-scale farmers using modern rice processing, positively impacted sustainability (Anugwa, Onwubuya, Chah, Abonyi, & Nduka, 2022). Rahman (2003) reported that when the education level was high, more farmers used modern rice processing than farmers with low education levels. Farmers with high education levels are more aware of the importance of adopting sustainable production practices such as modern rice processing because they are better informed about technological advances in agriculture and are more knowledgeable about the production and marketing of agriculture. On the other hand, low-education farmers tend to use traditional farming methods because they are unaware of the benefits of using modern rice processing methods (Amponsah, Addo, Dzisi, Asante, & Afona, 2018).

The modern rice milling experience of the small-scale farmers was statistically significant at 1% and positively related to the level of sustainability. Farmers utilizing modern rice processing techniques are embracing more sustainable practices. There are three main reasons for small-scale farmers in Nigeria choosing to adopt modern rice milling technologies over traditional rice processing techniques (Adisa, Ahmed, Ebenehi, & Oyibo, 2019; Obisesan, Salman, Adenegan, & Obi-Egbedi, 2018). Firstly, adopting new technologies reduces the time and effort involved in rice processing, ensuring that the rice is produced sustainably. Secondly, modern rice processing techniques produce better-quality rice (Joshi *et al.*, 2020). Thirdly, the high initial cost of adopting new machinery can be recovered through increased production. Therefore, small-scale farmers can improve their productivity and profitability by choosing the right rice processing technology.

The labor size of the small-scale farmers using modern rice processing was statistically significant at 1% and negatively related to the level of sustainability. Therefore, the smaller the labor size, the higher the sustainability level (Ahmed, Saha, Sarkar, & Alam, 2022). The sustainability index analysis strongly suggested that the level of sustainability was higher when the labor size of the farmers using modern rice processing was less than three laborers per hectare of paddy field. Therefore, indicating that optimizing labor size is crucial for enhancing sustainable agricultural practices among small-scale rice farmers.

The investment of the small-scale farmers using modern rice mills was statistically significant at 1% and positively related to the level of sustainability. The first contributing factor towards the sustainability of the small-scale farms that used the modern rice mill was their access to modern equipment through increased investments. There was a strong correlation between the accessibility to modern equipment and the level of sustainability in the agricultural sector (Kumari & Garg, 2021). Farmers with more modern machinery were more likely to achieve higher yield levels and better production efficiency when compared to those who did not have access to such machinery. As a result, these farmers could produce large quantities of rice for market sale with minimal cost and effort.

Modern rice processing has been recently gaining popularity as an environmentally friendly process. The processors use several techniques to reduce the water and energy needed to process rice. These techniques are washing, drying, threshing, and milling. The income of the small-scale farmers using modern rice mills was statistically significant at 10% and positively related to the level of sustainability. This finding suggests that farmers who invest in higher-efficiency equipment tend to produce greater profits than those who stick with traditional equipment. This effect is likely due to economies of scale in processing, i.e., as production increases, it becomes easier to maximize efficiency and increase profit. When assessing the sustainability of farming operations, it is crucial to consider both costs and benefits because increased production may carry hidden costs such as pollution or depletion of natural resources. In the case of modern rice processing, most of the machinery used is low-cost items that can be built by the owner or purchased with a small loan.

The cost of production, or the amount that a producer must expend to produce a unit quantity of rice, is statistically high at 1% and negatively related to the level of sustainability of the rice farmer using a modern method of rice processing. This finding means that as the cost of production increases, a farmer's sustainability level decreases. However, this relationship could be stronger. Therefore, other factors, such as the amount of rice produced per harvest and the cost to the farmer of his machinery, may be more important than the cost of production in determining the sustainability of the rice farmer. The other major factor that affects the sustainability and profitability of the rice farmer is the quality of the rice he produces.

The farmers' perception of economic sustainability was statistically significant at 10% and positively related to the sustainability of modern rice processing (see Table 3). This result implies that the perception of the farmers on the economic sustainability of modern rice processing is correlated with the level of its sustainability (Escobar *et al.*, 2022). On the other hand, the study showed that the technical complexity of modern rice processing is not significantly related to the perception of the farmers on its economic sustainability. In other words, the level of technological complexity does not affect the reliability of the output generated by the system in its effort to earn a living for the farmers and sustain their business in the long run.

This finding explored the farmers' perception of organizational sustainability using modern rice processing. The farmers' perception of organizational sustainability was statistically significant at 10% and positively related to the sustainability of farmers using modern rice processing. Based on the results of this study, there is a positive relationship between organizational sustainability and the level of technical innovation in an organization. Hence, the need to develop more sustainable organizations in the agricultural sector. This study shows a relatively close but not strict link between farmers' perceptions of their farms' sustainability and their rice processors' technical innovation. However, stronger relationships may exist between farmers' perceptions of the sustainability of their farms and the levels of the organization's environmental performance, as well as how they implement new technologies to improve sustainability.

Table 3- Factors affecting the sustainability index of the modern rice processing technique (Equation 4)

Power of classification of the sustainability index of the modern milling process				
	High	**Moderate**	**Low**	**Percent correct**
High	25	5	5	98
Moderate	12	11	2	96
Low	14	3	1	100
Overall percentage	63	25	10	98

Effect	**Model Fitting Criteria**	**Likelihood Ratio Tests**	
	-2 Log Likelihood of Reduced Model	**Chi-Square**	**p-value**
Intercept	55.801	2.601	0.045
Education level	85.248	7.541	0.0001
Sex	23.214	0.124	0.632
Experience	59.214	4.214	0.00341
Labor size	32.124	2.457	0.054
Investment	99.215	10.254	0.000155
Income	25.214	2.413	0.012
Cost of production (excluding cost of energy)	-45.214	-3.241	0.012
knowledge of climate change	42.013	3.417	0.024
Knowledge of economic sustainability	58.036	3.021	0.0214
Knowledge of business sustainability	78.215	6.275	0.000125
Cox and Snell	**Nagelkerke**	**McFadden**	
0.65	0.784	0.551	
Chi-square	89.254		

Conclusion

1. Small-scale rice farmers prefer traditional processing. The traditional approach was chosen due to the expensive cost of modern processing machines, which have a higher output than the traditional method.
2. While the nutritional content of rice processed using traditional techniques was deemed superior, farmers recognized the appearance of rice produced by modern methods as the most outstanding. The farm employsthe modern technique using different machines for rice processing, which impacts the environment; carbon emission levels and noise pollution were the significant environmental impacts of the modern rice processing technique.
3. The traditional technique of rice processing released high carbon into the environment, resulting in high water usage and, consequently, water pollution. The farmers who use the traditional technique care for the environment by reducing carbon emission energy and water use, while the farmers that use the modern technique care for the environment by reducing their water and energy use significantly.
4. Factors such as gender experience, labor size, investment, income, cost of production, knowledge of climate change, and business economic sustainability were the significant factors that influenced the farmers using the modern and traditional rice processing techniques to have a sustainability index.
5. The education level of the farmers and their knowledge of sustainability practices prompt them to prefer modern technology to traditional techniques.

Recommendation

There is a need to make recommendations based on the findings.

The Government needs to develop a

support program to reduce the cost of acquiring the machines required to use a modern rice processing technique. It will reduce the production cost of the farmers. Alternative energy sources need to be explored to reduce the impact of high carbon emissions on the environment.

Farmers should be educated about the value of using renewable energy sources to improve production and the environmental impact. The use of more modern machinery for paddy rice production should be encouraged to improve the output and quality of rice produced and reduce production costs.

Farmers should be encouraged to adopt modern farming techniques to reduce the impact of chemicals on the environment and adopt improved techniques to produce high-quality, healthy produce that satisfies consumer demands. Measures should be taken to reduce the waste from food processing. Incentives should be provided to encourage the use of renewable energy and reduce the use of fossil fuels in production. The use of modern technology needs to be encouraged in order to increase production and decrease costs.

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بررسی پایداری روش‌های سنتی فرآوری برنج در میان کشاورزان خرد برنج در جنوب شرق نیجریه

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چکیده

برنج یکی از غذاهای اصلی در سراسر جهان است، اما فرآوری آن به دلیل مصرف آب و انرژی و انتشار گازهای گلخانه‌ای، اثرات قابل‌توجهی بر محیط‌زیست دارد. در نتیجه، تولیدکنندگان برنج سعی می کنند روش‌های فرآوری پایدار را برای کاهش اثرات منفی زیست‌محیطی و افزایش سودآوری اتخاذ کنند. این مطالعه میزان پایداری روش‌های فرآوری برنج شالیزاری (شالی) مدرن و سنتی را در میان کشاورزان خرده‌مالک شالیکار در جنوب شرق نیجریه تحلیل می‌کند. داده‌ها از ۲۴۰ تولیدکننده برنج با استفاده از رویکردهای آماری مانند آمار توصیفی، شاخص پایداری (تحلیل نسبت ارزیابی وزن‌دهی) و تحلیل رگرسیون چندجمله‌ای جمع‌آوری شد. نتایج نشان داد که ۳۴/۷ درصد از کشاورزان شالیکار از روش‌های نوین و ۶۵/۳ درصد از روش‌های سنتی فرآوری استفاده می‌کردند. از نظر ۷۷ درصد کشاورزان خرده مالک، آسیاب کردن سنتی باعث انتشار میزان قابل‌توجهی گاز کربن می‌شود و همچنین ۶۸ درصد کشاورزان آلودگی صوتی را در حد بالایی ارزیابی می‌کنند. ۸۰ تا ۱۰۰ درصد کشاورزان خرده مالک که از تکنیک‌های مدرن استفاده می‌کنند به محیط‌زیست اهمیت می‌دهند و می‌خواهند انتشار گاز، زباله‌های جامد، مصرف انرژی و مصرف آب خود را کاهش دهند. شاخص پایداری در کشاورزانی که از روش‌های فرآوری سنتی یا مدرن استفاده می‌کنند تحت‌تاثیر جنسیت، تعداد نیروی کار، سرمایه‌گذاری، درآمد، هزینه تولید، میزان درک تغییرات آب و هوا و پایداری محیطی قرار می‌گیرد. این مطالعه استفاده از منابع انرژی تجدیدپذیر را برای افزایش بهره‌وری و کاهش اثرات زیست‌محیطی توصیه می‌کند.

واژه‌های کلیدی: آلاینده، اثرات زیست‌محیطی، انتشار گازهای گلخانه‌ای، سوددهی، سرمایه‌گذاری، مصرف انرژی

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