



## COMPARATIVE ASSESSMENT OF THE TECHNICAL EFFICIENCY OF MALE AND FEMALE BAMBARA NUT FARMERS IN NORTHEAST NIGERIA: A STOCHASTIC FRONTIER ANALYSIS APPROACH

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### ABSTRACT

The study comparatively assessed the technical efficiency of male and female Bambara nut farmers in Northeast Nigeria using the Stochastic Frontier Analysis (SFA) approach. A multi-stage sampling procedure was used to select a total of 360 male and 360 female smallholder Bambara nut farmers from the study area. Data were collected using a structured questionnaire and analysed using Cobb-Douglas stochastic frontier cost function model and independent sample z-test. Findings revealed that male and female Bambara nut farmers have a mean Technical Efficiency level of 0.759 and 0.849 respectively. Female Bambara nut farmers are significantly more technically efficient ( $z = -12.560$ ,  $p < 0.01$ ) than their male counterparts. The major drivers of technical efficiency for both genders were farm size, labour, seed quantity, and agrochemical use, all of which were significant at  $p < 0.01$ . Factors influencing technical inefficiency also varied by gender. For male farmers, farming experience, labour use, seed quantity, and agrochemical application were significant at  $p < 0.01$ , while age, household size, cooperative membership, distance to farm, banditry/herdsmen attacks and training in Bambara nut farming were significant at  $p < 0.05$ . For female farmers, education, farming experience, cooperative membership, land ownership, and off-farm income were significant at  $p < 0.01$ , whereas age and herdsmen attacks were significant at  $p < 0.05$ . The study concluded that female Bambara nut farmers are more technically efficient than their male counterparts. Gender-sensitive agricultural extension services and training schemes need to be reinforced, in particular with attention to the inclusion of male farmers.

**Keywords:** Technical Efficiency, Male, Female, Bambara Nut, Northeast Nigeria

### INTRODUCTION

Agricultural development is a critical concern globally and more so in Sub-Saharan Africa, where food security problems persist despite huge investments and policy actions (Hemathilake and Gunathilake, 2022; Ogunlesi *et al.*, 2018). Wide fluctuations in food supply, low agricultural productivity and inadequate resource use continue to characterise this region and threaten sustainable rural livelihoods. Hence, one pathway to food and income security will be to exploit the potential of underutilised crops like Bambara nut (BG), a drought-tolerant legume with enormous nutritional and agronomic value (Onuche *et al.*, 2020). Bambara nut cultivation in Nigeria is still marginal compared to other legumes like cowpea and groundnut, especially due to limited commercialisation, poor market integration and low input efficiency. Smallholder farmers, mainly women, mainly grow the crop using traditional techniques that often constrain technical performance (Mubaiwa *et al.*, 2018). However, its capacity to grow on poor soils and in arid climates, as well as its protein-rich profile, indicates that it is relevant for contemporary agricultural diversification strategies to reduce poverty and climate resilience.

Performance disparities in farming enterprises are associated with the concept of technical efficiency. Technical efficiency is defined as the ability of a producer to obtain maximum output from a given set of inputs using current technology, which serves as a proxy for managerial ability and input use optimisation (Katcha, 2023; Onuche, 2020). With regards to Bambara nut production, where resources are limited and access to modern technologies is not uniform, assessing technical efficiency is important to designing evidence-based interventions. In addition, the technical efficiency studies



are particularly important in Nigeria's northeast region, which is socioeconomically fragile and highly gendered in terms of access to productive assets, extension services and decision-making (FAO, 2020; Henry *et al.*, 2023). These disparities tend to show up in different technical outcomes for male and female farmers. It is imperative to understand these differences so that agricultural development can be equitable and policy formulation is informed. The use of Stochastic Frontier Analysis (SFA) is thus appropriate, as it allows for the estimation of efficiency scores while accounting for measurement errors and environmental stochasticity inherent in smallholder agriculture.

Despite government and donor efforts aimed at revitalising the Nigerian agricultural sector, many farming communities remain entrenched in poverty due to low productivity and inefficiency in resource use (Dagachi and Olorunsanya, 2023). Bambara nut farming is a beneficial practice in terms of soil fertility and food security, but it is not much embraced in the northeast region. Lack of improved inputs, primitive agriculture techniques and poor market support are limiting its production. In addition, empirical evidence is not available to assess how efficiently farmers are converting their inputs into outputs, and the evidence that does exist is limited to gender differences. These inefficiencies are compounded by gender-based inequalities. Although women are the primary cultivators of Bambara nut, their limited access to land, credit, and extension services diminishes their capacity to adopt best agronomic practices and optimise input use (Joe-Nkamuke *et al.*, 2019). On the contrary, men also cultivate it, but the level of technical efficiency is not clear. Disaggregated data on gender-specific technical efficiency outcomes are not available, which hinders the formulation of targeted policies and programmes. The increasing population growth rate of 2.6 per cent annually in Nigeria (World Bank, 2020) implies greater pressure on arable land, reducing the scope for productivity gains through farm expansion. Therefore, it becomes not only desirable but necessary to improve technical efficiency by using the resources available. However, the technical efficiency of Bambara nut farmers in Northeast Nigeria has not been studied before, and the few studies on gender-specific disparities in technical efficiency have not used robust methodologies such as stochastic frontier analysis. This study addresses these gaps by evaluating and comparing the technical efficiency of male and female Bambara nut farmers as well as identifying the key determinants driving efficiency and inefficiency differentials among these two groups of farmers in the northeast region of Nigeria. The objectives of the study were to:

- i. estimate the technical efficiency of male and female Bambara nut farmers;
- ii. compare the technical efficiency of male and female Bambara nut farmers,
- iii. analyse the determinants of technical efficiency in Bambara nut production along gender line.

## **MATERIALS AND METHODS**

### **The Study Area**

This study was carried out in the Northeast region of Nigeria. Northeast Nigeria is one of the six geographical zones in Nigeria and comprises six states, namely, Adamawa, Bauchi, Borno, Gombe, Taraba and Yobe. It lies in between the Republics of Chad and Cameroon to the east, Plateau and Benue States to the south, Kano and Jigawa States to the west and the Niger Republic to the north. It is bounded by latitude 7° 30' to 14° North and longitude 9° to 15° East of the Greenwich meridian. The region covers only about one third of the area of Nigeria and holds a population of 26 million people, or 12% of Nigeria's population (Worldometer, 2021). In the area, major crops grown are cassava, rice, yam, maize, millet, potato, sorghum, cowpea, cotton, groundnut, Bambara nut and watermelon (Ojanuga, 2006). Rearing of livestock is also known of the farmers. Annual average rainfall in the area is between 250 mm near Nguru (Borno State) and 1310 mm around Sugu (Adamawa State), while annual average temperature is between 20°C and 40°C (NAERLS/PCU, 2014). The vegetation zones of the Sahel, Sudan, and Guinea Savanna cut across the region. The climatic condition of the area consists of two seasonal variations, which are dry and wet seasons. The dry season occurs from October to April, while the wet season takes place from June to September, with a slight break in August, commonly referred to as the August break. In this area, the Bambara nut is also grown widely as a seasonal legume during the rainfall season.



### Sampling Procedure and Sample Size

A multi-stage sampling was employed in selecting respondents for this study. In the first stage, purposive sampling method was used to select three out of the six States in the zone. The States selected for the study were Adamawa State, Bauchi State and Taraba State due to evidence of valid or contact household farmers who cultivates Bambara nut. The second stage involves a purposive selection of six local government areas from each of the selected states based on the concentration of Bambara nut household farmers, giving a total of eighteen (18) local government areas. In the third stage, two communities were randomly selected from each L.G.As, giving a total of thirty-six (36) communities. A stratified random sampling technique was employed to select ten (10) female and ten (10) male Bambara nut farmers from a convenient population of each community to give 360 male and 360 female Bambara nut farmers. For this study, a total of seven hundred and twenty (720) Bambara nut farmers were used. The list of Bambara Nut farmers in the selected communities which constitutes the sampling frame was compiled with the assistance of staff of the Agricultural Development Programme (ADP), resident extension agents, officials of farmers' associations and community leaders.

### Methods of Data Collection and Analytical Tools

Data were collected through the use of a structured questionnaire which was used as an instrumental guide to interview the respondents personally. Information collected from respondents includes; their personal characteristics, farm size, farm income, farm operations, quantity of output produced, distance to farmland and total labour used among others.

The collected data were analysed using the SFA model and independent samples Z-tests.

The Cobb-Douglas Stochastic frontier production function that was used to determine the technical efficiency of male as well as female Bambara nut farmers in northeast Nigeria is expressed in its implicit form as used by Dagachi and Olorunsanya (2023) and Tenaye (2020) as:

$$Y_i = f(X_i, \beta) e_i \dots\dots\dots (1)$$

$$e_i = v_i + u_i \dots\dots\dots (2)$$

where;  $Y_i$  = Quantity of output of the  $i^{th}$  farm (kg),  $X_i$  = Vector of inputs used by the  $i^{th}$  farm,  $B$  = Vector of parameters to be estimated,  $e_i$  = Farm specific composite error term,  $v_i$  = Random error outside farmer's control,  $u_i$  = Technical inefficiency effects.

Explicitly, the Cobb-Douglas stochastic frontier production function is specified as follows:

$$\ln Y = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + (v_i + u_i) \dots\dots\dots (3)$$

where;  $\ln$  = Natural logarithm,  $\beta_0$  = Constant term,  $\beta_1 - \beta_5$  = Regression coefficients,  $X_1$  = Farm size (ha),  $X_2$  = Quantity of seed sown (kg),  $X_3$  = Quantity of fertilizer (kg),  $X_4$  = Total labour used (mandays), and  $X_5$  = Agrochemical used (litres).

The difference between the technical efficiency of male and female BG farmers (hypothesis 1) was tested using the independent sample z-test distribution. The independent sample z-test distribution is fitted as:

$$Z_{cal} = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s^2_{\bar{x}_1}}{n_1} + \frac{s^2_{\bar{x}_2}}{n_2}}} \dots\dots\dots (4)$$

where;  $\bar{x}_1$  is the mean of technical efficiency of male Bambara nut producers,  $\bar{x}_2$  is the mean of technical efficiency of female Bambara nut producers,  $s^2_{\bar{x}_1}$  is the standard deviation of technical efficiency of male Bambara nut producers,  $s^2_{\bar{x}_2}$  is the standard deviation of technical efficiency of female Bambara nut producers,  $n_1$  is the numbers of male respondents, and  $n_2$  is the numbers of female respondents. The determinants of technical inefficiency which represents the factors that determine Bambara nut production for male and female farmers in northeast Nigeria is specified as:

$$U_i = \delta_0 + \delta_1 \ln W_1 + \delta_2 \ln W_2 + \delta_3 \ln W_3 + \delta_4 \ln W_4 + \delta_5 \ln W_5 + \dots\dots + \delta_{12} \ln W_{12} + \delta_{13} \ln W_{13} \dots\dots\dots (5)$$

where;

$W_1$  = age of farmer (years)

$W_2$  = level of education (years of formal schooling)



$W_3$  = household size (number of people per farmer's household)  
 $W_4$  is the farming experience of the farmer (number of years in Bambara nut production)  
 $W_5$  is the extension visits (number of visits per production cycle)  
 $W_6$  is the cooperative membership (1 = Member; 0 = Non-member)  
 $W_7$  is the amount of credit obtained (₦)  
 $W_8$  is the distance to farm (Km)  
 $W_9$  is the banditry/herdsmen attacks (Dummy, Yes = 1; No = 0)  
 $W_{10}$  is the perceived price hike of the product (Dummy, Yes = 1; No = 0)  
 $W_{11}$  is the land ownership status (Inheritance = 1; Otherwise = 0)  
 $W_{12}$  is the training in Bambara nut farming (Yes = 1; No = 0)  
 $W_{13}$  is the off-farm income (₦)  
 $\delta_0$  is the constant, and  $\delta_1$ – $\delta_{13}$  is the parameters to be estimated.  
 Given that the actual production typically falls below the frontier production ( $Y_i \leq Y_i^*$ )  
 The feasible range for technical efficiency (TE) lies between 0 and 1.  
 A TE value of 1 signifies that the actual production equals the frontier production, thereby indicating that the farm is deemed to be technically efficient (Bravo-Ureta *et al.*, 2020).

## RESULTS AND DISCUSSION

### Estimation of the Technical Efficiency of Male and Female Bambara -nut Farmers

The Cobb-Douglas Stochastic Frontier Production Function (SFPF) was employed to assess the technical efficiency of both male and female Bambara nut farmers in Northeast Nigeria. The technical efficiency score for each group of farmers is presented in Table 1.

**Table 1:** Level of Technical Efficiency of Male and Female Bambara-nut Farmers in Northeast Nigeria

Technical Efficiency Level	Male		Female	
	Frequency	Percent	Frequency	Percent
0.201 – 0.400	12	3.3	-	-
0.401 - 0.600	34	9.4	10	2.8
0.601 - 0.800	173	48.1	73	20.3
0.801 - 1.000	152	42.2	277	76.9
Total	360	100	360	100
Mean	0.759		0.849	
Maximum	0.922		0.971	
Minimum	0.333		0.401	

Source: Field survey data, 2024

Table 1 reveals the technical efficiency scores of Bambara nut (BG) farmers in the Northeast region. For male farmers, the scores range from a minimum of 0.333 to a maximum of 0.922, with almost half (48.1%) achieving scores between 0.601 and 0.8. The smallest group (3.3%) had scores between 0.201 and 0.4, resulting in a mean technical efficiency (TE) score of 0.759. Female BG farmers, on the other hand, exhibited TE scores ranging from 0.401 to 0.971. The majority (76.9%) scored above 0.8, with the smallest group (2.8%) scoring between 0.401 and 0.6, leading to a mean TE score of 0.849. This data indicates that female BG farmers possess higher TE scores than their male counterparts, suggesting that although both groups are technically efficient, female farmers demonstrate superior efficiency and commitment to Bambara nut farming. The superior efficiency among female farmers could be attributed to their meticulous management and optimisation of available resources, which justifies their higher productivity in the study area. Recent empirical studies, such as those by Ragasa *et al.* (2013), support the finding that women often achieve higher productivity when given equal access to resources, underscoring the importance of empowering female farmers to enhance overall agricultural productivity. The finding that female Bambara nut farmers are more technically efficient than their male counterparts implies that they are more





productive, better at optimising resources, and more likely to adopt new technologies. This stresses the importance of gender-sensitive agricultural policies and programmes that target female farmers, providing them with the necessary support and resources to enhance their technical efficiency. The World Bank (2019) noted that gender-sensitive agricultural policies and programmes that target female farmers can help bridge the gender gap in agriculture and promote gender equality. Empowering female farmers can lead to increased agricultural productivity and food security and challenge the common perception that male farmers are more efficient. Quisumbing *et al.* (2021) noted that supporting female farmers can unlock their potential to contribute significantly to agricultural development and food security. Therefore, female farmers should be supported and empowered to contribute significantly to agricultural development and food security, as they have been shown to be more technically efficient in the production of crops like Bambara nut.

#### **Comparison of the Technical Efficiency of Male and Female Bambara-nut Farmers**

To determine if there is a statistically significant difference in technical efficiency between male and female Bambara nut farmers in Northeast Nigeria, an independent sample z-test distribution was applied. These results which are shown in Table 2, give a complete analysis of the comparison of technical efficiency metrics between the two groups and clarify the gender based technical efficiency gap in agricultural practises in the study area.

**Table 2:** Difference in Technical Efficiency between Male and Female Bambara-nut Farmers in Northeast Nigeria

Group	Mean	Std. Deviation	Std. Error Mean	Df	z-statistic
Male	0.759	0.108	0.006		
Female	0.849	0.097	0.005		
Difference	-0.090	0.136	0.007	718	-12.560***

Source: Field survey data, 2024

Note: \*\*\* signifies 1% level of significance.

The results in Table 2 showed that average technical efficiency score of female farmers is significantly higher than that of their male counterpart ( $z = -12.560$ ,  $p < 0.01$ ). The result implies that female Bambara nut farmers are more technically efficient than male farmers in the study area. This higher technical efficiency amongst female BG farmers is consistent with Solomon *et al.*, (2015), Dossah & Mohammed, (2016) and Julien *et al.*, (2023) who show that female farmers, on average, have higher technical efficiency than male farmers given similar resource and support. Such studies prove that helping women in agriculture can positively influence the entire agricultural sector in the region.

#### **Determinants of Technical Efficiency of Male and Female Bambara-nut Farmers**

The result of the maximum likelihood estimates of the stochastic production frontier analysis of male and female Bambara nut farmers in northeast Nigeria was achieved using Frontier 4.1c and the result is presented in Table 3. The analysis of the maximum likelihood estimation of the stochastic frontier production function and technical inefficiencies in Bambara nut production in Northeast region of Nigeria for male and female farmers showed that for the male model, the results of the stochastic frontier production model revealed that all estimated coefficients of the production function variables are significant, except for farm size and quantity of fertiliser used. The coefficients for labour, quantity of Bambara nut seed planted, and quantity of agrochemicals (herbicides and pesticides) used are all significant at the ( $P < 0.01$ ). This implies that labour, the quantity of Bambara nut seed planted, and the quantity of agrochemicals used remain important contributors to the improvement of technical efficiency in Bambara nut production practiced in the state.

**Table 3:** Maximum Likelihood Estimates of the Stochastic Production Frontier Analysis of Male and Female Bambara-Nut Farmers in Northeast Nigeria

Variable	Parameters	Male		Female	
		Coefficient	t-value	Coefficient	t-value
Constant	$\beta_0$	1.908***	5.123	1.572***	17.418
Farm size (Hectares)	$\beta_1$	0.076	1.208	1.040***	4.097
Labour(Man-days)	$\beta_2$	0.270***	3.024	0.063***	3.965
Bambara nut seed (Kg)	$\beta_3$	0.316***	4.141	0.077***	2.418
Fertilizer used (Kg)	$\beta_4$	0.106	1.377	-0.026	-1.689
Agrochemicals (Litres)	$\beta_5$	0.497***	5.102	0.315***	9.349
<b>Inefficiency Model</b>					
Constant	$\delta_0$	2.193***	6.540	7.224***	7.688
Age of farmer	$\delta_1$	-0.715**	-2.332	-0.349**	-2.303
Level of education	$\delta_2$	0.039	0.308	0.329***	5.373
Household size	$\delta_3$	0.381**	2.447	0.771	1.562
Farming experience	$\delta_4$	0.131***	9.593	0.341***	5.210
Extension visits	$\delta_5$	-0.772	-1.228	9.646	1.064
Cooperative membership	$\delta_6$	-0.325**	-2.113	0.548***	4.726
Amount of credit obtained	$\delta_7$	0.008	0.473	0.076	1.396
Distance to farm	$\delta_8$	-0.184**	-2.602	0.117	1.415
Banditry/herdsmen attacks	$\delta_9$	-0.183**	-2.240	-0.296**	-2.615
Perceived price hike	$\delta_{10}$	-0.279**	-2.478	0.385	1.488
Land ownership status	$\delta_{11}$	-0.077	-0.585	0.375***	5.457
Training in Bambara farming	$\delta_{12}$	-0.071**	-2.340	-0.448***	-3.428
Off farm income	$\delta_{13}$	0.012	0.084	0.471***	7.952
Sigma-squared		0.398***	5.854	0.372***	13.555
Gamma		0.882***	12.337	0.949***	18.511
LR test		49.370		42.356	
Log likelihood function		98.847		165.457	

Kodde and Palm 1986 LR critical value = 34.167 at 1% and 28.268 at 5% significant levels.

**Source:** Field survey data, 2024

**NB:** \*\*\* signifies 1% level of significance, \*\* signifies 5% level of significance, \* signifies 10% level of significance.

The sigma-square ( $\sigma^2$ ) value of 0.398, significant at the ( $P < 0.01$ ), confirms the model's goodness of fit and the correctness of the composite error distributional assumptions. The gamma value ( $\gamma$ ) of 0.882 indicates that 88.2% of the variation in Bambara nut output is due to technical inefficiency. Moreover, the presence of technical inefficiency was tested by the Likelihood Ratio (LR) test, which was 49.370. Therefore, the null hypothesis of no technical inefficiency was rejected. The generalised likelihood test value of 98.847 indicates that the stochastic frontier model with inefficiency terms fits the data significantly better than the traditional average production function (APF) model without the inefficiency terms. This further means that there is significant inefficiency in the production process of Bambara nuts, as male farmers are not fully technically efficient. The inefficiency model shows that the age of the male BG farmers had a negative relationship with their technical inefficiency at the 5% level of significance. This implies that as the age of male BG farmers increases, their technical inefficiency reduces and vice versa. This further suggests that older farmers tend to be more technically efficient due to their accumulated experience and knowledge, which helps them manage farm operations better than younger male farmers. This finding aligns with Musa *et al.* (2021), who reported a negative relationship between age and technical inefficiency. Household size had a positive relationship with technical inefficiency, significant at the 5% level. This implies that larger household sizes are associated with increased technical inefficiency. Larger households may create additional financial and social burdens, potentially diverting attention and resources away from efficient farm management. This finding contrasts with Mahmud (2022) and Abdu-Raheem *et al.* (2023), who found a negative relationship between household size and inefficiency.



Farming experience had a positive relationship with technical inefficiency, significant at the ( $P < 0.01$ ). This implies that as farming experience increases, technical inefficiency also increases, suggesting that more experienced farmers might rely on traditional methods, which may not be the most efficient. This finding contradicts the study by Ochi *et al.* (2016) and Berhan (2016), who reported that farming experience enhances technical efficiency. Cooperative membership showed a negative relationship with technical inefficiency at the ( $P < 0.05$ ) level of significance. This implies that male BG farmers who are members of cooperatives experience reduced technical inefficiency. Cooperative membership provides better access to resources, information, and credit, which can help farmers improve their efficiency. This finding aligns with Olagunju *et al.* (2021), who reported a positive impact of cooperative membership on reducing inefficiency.

Distance to farm had a negative relationship with technical inefficiency, significant at the ( $P < 0.05$ ). This implies that male BG farmers whose farms are farther from their homes experience reduced inefficiency. This counterintuitive result may suggest that farmers with distant farms are more likely to adopt efficient farming techniques due to the increased effort required to manage these farms. Such distance will cause a farmer to set out on time to farm and be very determined to cover a serious share of the labour or other farm management activities per visit without procrastination that may probable be common with nearby farms. This finding contrasts with the traditional views of Eze and Anyiro (2021) that proximity to farmland enhances efficiency. The results reveal that banditry and herdsmen attacks had a negative relationship with technical inefficiency at the 5% level of significance. This finding suggests that as the frequency and intensity of these security threats increase, the technical inefficiency among farmers decreases. This counterintuitive result may imply that farmers are compelled to adapt their practices in response to these threats, inadvertently enhancing their efficiency through improved risk management strategies. Farmers facing insecurity may become more innovative and strategic in their operations, adopting practices designed to mitigate risks while maximizing output. For instance, they might implement more efficient resource allocation, optimize labour utilization, or employ alternative farming methods that are more resilient to disruptions. This notion aligns with the concept of localized resilience, wherein farmers develop coping strategies to navigate the challenges posed by insecurity. This finding stands in contrast to the prevailing view that insecurity undermines agricultural productivity. Adamu and Jibrin (2023) highlight this phenomenon, suggesting that the traditional narrative surrounding insecurity may be evolving. Moreover, the necessity to adapt to banditry and herdsmen attacks compels farmers to devise innovative strategies to maintain their livelihoods and ensure food security for their families. These strategies might include altering farming schedules to avoid peak attack times, negotiating financial arrangements with bandit groups, or engaging in shared arrangements regarding their produce. By doing so, farmers may not only sustain their operations but also enhance their overall efficiency in the face of adversity. This finding contrast with Okeke and Onwumere (2022), who found that insecurity in farming communities significantly reduces agricultural productivity. Perceived price hikes had a negative relationship with technical inefficiency at the 5% level of significance. This implies that as farmers anticipate or experience price increases, their technical inefficiency decreases, potentially due to a heightened focus on maximizing productivity and resource management in the face of rising costs. This finding aligns with the study by Chikezie *et al.* (2020), who reported that market uncertainties could push farmers to enhance efficiency. Training in Bambara farming had a negative relationship with technical inefficiency at the 5% level of significance. This implies that male BG farmers who receive training in Bambara nut farming experience reduced inefficiency, likely due to the adoption of improved farming practices and better resource management learned through training. This finding aligns with the study by Ojo *et al.* (2022) and Adeoye and Oladele (2020), who reported that training in specific crop production improves technical efficiency.

For female Bambara nut farmers, the results of the stochastic frontier production model reveal that all estimated coefficients of the production function variables are positive and significant except the quantity of fertiliser used. Farm size, labour, and quantity of agrochemicals (herbicides and pesticides) used are significant at the 1% level, while the quantity of Bambara nut seed planted was



significant at the 5% level, indicating that these factors are essential for improving the technical efficiency of female farmers in Bambara nut production. The sigma-square ( $\sigma^2$ ) value of 0.372, significant at the 1% level, confirms the model's goodness of fit and the correctness of the composite error distributional assumptions. The gamma value ( $\gamma$ ) of 0.949 indicates that 94.9% of the variation in Bambara nut output is due to technical inefficiency. Moreover, the presence of technical inefficiency was tested by the Likelihood Ratio (LR) test, which was 42.356. Therefore, the null hypothesis of no technical inefficiency was rejected. The generalised likelihood test value of 165.457 indicates that the stochastic frontier model with inefficiency terms fits the data significantly better than the traditional average production function (APF) model without the inefficiency terms. This further means that there is significant inefficiency in the production process of Bambara nuts, as female farmers are not fully technically efficient.

The inefficiency model shows that the age of the female BG farmers had a negative relationship with their technical inefficiency at the 5% level of significance. This implies that as the age of female BG farmers increases, their technical inefficiency reduces and vice versa. This further suggests that older farmers tend to be more technically efficient due to their accumulated experience and knowledge, which helps them manage farm operations better than younger female farmers. This finding aligns with Bello *et al.* (2021), who reported a negative relationship between age and technical inefficiency. The model shows that the level of education had a positive relationship with technical inefficiency and is significant at the ( $P < 0.01$ ). This implies that higher educational attainment increases technical inefficiency among female BG farmers. This suggests that female farmers with more education may be less focused on farming, possibly due to diversifying into non-farm activities, thereby decreasing their efficiency in farming operations. Farming experience had a positive relationship with technical inefficiency, significant at the 1% level. This implies that as farming experience increases, technical inefficiency also increases. This suggests that more experienced female farmers might rely on traditional methods that are less efficient. This finding contrasts with Ochi *et al.* (2016) and Berhan (2016), who reported that farming experience enhances technical efficiency. Cooperative membership had a positive relationship with technical inefficiency and was significant at the 1% level. This implies that female BG farmers who are members of cooperatives experience increased technical inefficiency. This unexpected result may suggest that cooperative participation might distract from core farming activities or that some cooperatives are not providing effective support for efficiency improvement. This finding contrasts with Bello and Sani (2022), who reported a positive impact of cooperative membership on reducing inefficiency. Banditry/herdsmen attack had a negative relationship with technical inefficiency and was significant at the 5% level. This implies that as banditry and herdsman attacks increase, technical inefficiency decreases, suggesting that female farmers may have developed adaptive strategies to maintain efficiency in the face of insecurity. This finding contrasts with Adamu *et al.* (2023) and Okeke and Onwumere (2022), who reported that insecurity reduces technical efficiency. Land ownership status had a positive relationship with technical inefficiency and was significant at the 1% level. This implies that female BG farmers who own land tend to have increased technical inefficiency. This result may be due to the fact that land ownership provides a sense of security, which might reduce the urgency to maximize farm output, leading to less efficient farming practices. This finding contrasts with Adetayo (2021), Bello and Sani (2022), and Adetunji *et al.* (2023), who found that land ownership enhances technical efficiency. Training in Bambara farming had a negative relationship with technical inefficiency and was significant at the 1% level. This implies that female BG farmers who received training in Bambara nut farming experience reduced inefficiency, likely due to improved farming practices learned through training. This finding aligns with the study by Ojo *et al.* (2022) and Adeoye and Oladele (2020), who reported that training in specific crop production improves technical efficiency. Off-farm income had a positive relationship with technical inefficiency, significant at the 1% level. This implies that an increase in off-farm income leads to higher technical inefficiency, as female farmers may prioritize off-farm activities over their farming operations, thereby reducing their focus and efficiency. This finding aligns with Adeoye *et al.* (2023), who reported that off-farm income can divert attention from farming, leading to lower technical efficiency.





## CONCLUSION AND RECOMMENDATIONS

This study concluded that there is a significant gender-based difference in the technical efficiency of male and female BG farmers in the study area. Female Bambara nut farmers were found to be more technically efficient than their male counterparts. Also the technical efficiency of male farmers was largely explained by labour, quantity of Bambara seeds planted and application of agrochemicals, while age, household size, farming experience, membership in cooperatives, distance to farmland, banditry and herdsmen attacks, perceived price hikes and training in Bambara nut farming determined their technical inefficiency. The technical efficiency of female farmers is determined by farm size, labour and the application of agrochemicals, while age, level of education, years of farming experience, cooperative membership, banditry and herdsmen attacks, land ownership status, training in Bambara nut farming and off-farm income determine the technical inefficiency. Based on the findings, the study recommends that, there is a need to develop programmes that utilise the aptitude of female farmers to improve Bambara nut production in the nation in general. Such programmes should focus on resource management, decision-making and optimisation practices shown by female farmers, leading to higher technical efficiency. Furthermore, the efficient practices of female farmers should be transferred to male farmers through collaborative workshops and training sessions to enhance their resource management, decision-making and optimisation practices so as to attain higher technical efficiency that is needed to transform the agricultural sector and fight food insecurity through the cultivation of underutilised crops like Bambara nut in the region in particular and the nation at large. Any policy geared towards improving the technical efficiency of male and female farmers in the study area should be directed towards the important factors that determine their technical inefficiency while addressing security challenges of banditry and herdsmen attacks through community-based interventions and enhanced law enforcement.

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