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Article

Food security drive and adoption of improved rice varieties on the production efficiencies of upland and lowland rice farmers in north-central Nigeria

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Abstract: To attain the food security target of the country, fostering farmers' adoption of improved rice varieties will go a long way toward closing the lingering production deficit gap in Nigeria, and meeting up with the ever-increasing demand for rice consumption in the country. This study investigated the effect of the adoption of improved rice varieties on the production efficiencies of rice farmers in the north-central Nigeria. A multistage sampling technique was uses to select 387 rice farmers, which includes 201 upland and 186 lowland rice farmers in the study area. A stochastic frontier analytical model (SFA) was employed to estimate production efficiencies (technical, economic and allocative) for the rice farmers. Further, a multivariate regression analysis (MVA) was applied to determine the effect of adoption on the efficiency levels of the rice farmers. The exploratory analysis of the data revealed that the rice varieties available for adoption by the rice farmers in the study area is 10, but both upland and lowland rice farmers adopted more of two rice varieties (Faro-46 and Faro-52). From the SFA results, most of the rice farmers have mean technical, economic and allocative efficiencies of 0.7, 0.54 and 0.76 respectively. The SFA estimates also indicated that seed, herbicide, fertilizer, farm size and capital assets significantly affect the efficiency of upland rice farmers, while the efficiency of their lowland counterparts is influenced by seed, farm size capital and herbicide, amongst others. The MVA estimates also showed that the adoption rate of improved rice varieties, years of formal education, and farm-level factors made significant contributions to the efficiency levels of the rice farmers. Importantly, the levels of adoption of all rice varieties by farmers indeed influenced their technical and economic efficiency, while having no impact on their allocative efficiency. The study recommended that the government, research institutes and developmental agencies should promote easy access to improved rice varieties by farmers, as this can further drive sustained adoption. This can evidently help to achieve desirable yield and enhance the efficiency level of the rice farmers and boost food availability and achieve the zero-hunger target in the study area and Nigeria at large.

Keywords: adoption; rice production; efficiency; stochastic frontier; multivariate; Nigeria

1. Introduction

Sub-Saharan Africa and Africa in general are characterized with diverse environmental and agro-climatic conditions that require sustainable farming activities and improved seed technologies to achieve the desired increase in crop production, improvement in food security status, and enhancing the resource poor rural farmers' income (Keyser et al., 2015). This vision, which is in line with the United Nations zero hunger targets was embraced by the National Agricultural Seed Council of Nigeria with its investment in seed technologies (Awotide et al., 2013). It is on record that 5%–10% of the national seed requirement in Nigeria comes from certified seed, while the rest emanate from the locally produced seed and/or the seed preserved by the farmers from their previous harvests (FMARD, 2010). The non-availability of certified or improved seed is worrisome and presents a challenging situation to achieve sustained food security, and crop productivity growth in Nigeria, especially with many of the country's cultivated arable crops, including rice.

Rice crop (*Oryza sativa*) is a popular food crop cultivated by farmers and consumed by majority of the people, world over. Being a staple food crop that is also commonly produced and consumed in several African nations, it represents a major part of the households' diet, and an important source of income to the farmers (Merem et al., 2017). Apart from these importance, cultivation of the crop is also a source of employments and livelihood activities to about 80% of the people in the producing areas, given various activities involved along the production and distribution chains to the final consumers (Ogundele and Okoruwa, 2006 as cited in Bello, Baiyegunhi and Danso-Abbeam, 2021).

Despite the fact that rice is a cereal that strongly contributes to food security in Nigeria, domestic production is yet to meet the demand of the populace (Baiyegunhi and Danso-Abbeam, 2021), because of its rising demand which is associated with population surge and rural-urban movement (Amaechina and Eboh, 2017 as cited in Bello et al., 2021). According to Ayinde et al. (2016) as cited in Bello et al. (2021), the demand for rice was estimated to be 6.3 million tonnes in 2016, while the national supply was about 2.3 million tonnes (FMARD, 2016).

This ugly situation has led to importation of rice to fill up the production deficit, which comes with its consequences on the Nigerian populace and the country's economy. This scenario is a complete departure from the right direction for a country that was once one of the leading exporters of rice, globally (Ogunya, Bamire and Ogunleye, 2017). In lieu of this, the need is of importance to boost local production and supply of rice by adopting agricultural innovations and technologies such as improved crop varieties, which have been demonstrated to be productivity-enhancing, and rewarding to the farmers and the populace.

According to Tsado et al. (2014) as cited in Adenuga et al. (2016), rice production in Nigeria is dominated by smallholder farmers who are contributing significantly to the agri-food sector and food supply chain in Nigeria. According to Loko et al. (2022), smallholder farmers in Nigeria, and many other African countries, are mostly characterized with the use of cultural and traditional farming practices, resulting in poor yield, and low farmers' income. Farming operations are confronted with the use of low quality and low yield recycled seed, inadequate improved seed varieties, pests and diseases, climate extreme events, and other dynamics beyond the control of the resource poor farmers (Adenuga et al., 2016; Musaba and Muyendekwa, 2022).

Given the positive roles of agri-food sector to national growth in Nigeria, the government introduced and implemented some policies and programmes in the past, aimed at improving the sector and ensure food security at all levels (Nwaobiala and

Ubor, 2016; Okunola, 2016). Some of these programmes include; National Accelerated Food Production Programme (NAFPP), River Basin Development Authorities (RBDA), Operation Feed the Nation (OFN), Agricultural Credit Scheme (ACGS), Green Revolution (GR), Agricultural Development Programme (ADP), Directorate of Food, Roads and Rural Infrastructure (DFRRI), and the National Land Development Authority (NALDA) among others. Similarly, Fadama Development Project, National Special Programme for Food Security, Community and Social Development Projects, and the Agricultural Transformation Agenda (ATA) were also initiated by the government some years back. These programmes were implemented nationally to drive increased access to farmlands through various policies and reforms, investment in rural and critical infrastructure, boost access to grant in the form of input subsidies and, most importantly, boost agricultural productivity and achieve the zero hunger targets of the country (Nwaobiala and Ubor, 2016; Okunola, 2016).

However, despite all the interventions to improve food security through various policies and programmes, the Nigerian agri-food sector is facing lots of challenges where food supply falls short of food demand by the populace, and this production deficit gap was attributed to different issues confronting the farming sector in Nigeria, which are mostly economic and political in nature (Mgbenka and Mbah, 2016), and more importantly, farmers' lackluster attitude towards new agricultural innovations. Other challenges linked to the abysmal performance of the agri-food sector as highlighted in Oyediran et al. (2014) include poor investment in new agricultural technologies and infrastructures, poor adoption of existing improved technologies, as well as hostile investment climate of the nation.

From the aforementioned, sustainable food production and agricultural development in Nigeria appear increasingly challenging without embracing and disseminating yield increasing and cost-effective agricultural technologies to produce sufficient food, and to be able to meet up with the increasing demand of people in the country (Chandio and Yuansheng, 2018; Bello et al., 2020). Indeed, adoption of improved agricultural technologies can be a pathway for the farmers to boost food production and reduce the incidence of food insecurity, which by extension reduces food price hike, and make accessibility of food easy to the populace. Suffice it to say that, adoption of agricultural technologies, such as high yielding seed varieties is very germane in developing countries like Nigeria where agriculture and agricultural related activities represent the predominant livelihood activities of the populace. This is a policy relevant issue requiring urgent attention in a bid to reduce the prevailing inequality and poverty, as well as promoting the realization of zero hunger targets of the nation.

In lieu of the above background information, the objectives of this research were to: analyze the production efficiencies (technical, economic and allocative) of upland and lowland rice farmers in the North Central zone of Nigeria, examine the levels of adoption of improved rice varieties, and analyze the effect of adoption of improved rice varieties on the production efficiencies of rice farmers in the study area. All these are very germane for identifying key relevant indicators and initiating policy relevant actions towards these areas to scale up adoption of improved rice varieties for agricultural development both locally and nationally.

2. Technology adoption models in the agricultural sector

One of the effective strategies of enhancing productivity of the agricultural sector is through innovations. The technological inventions in agricultural sector coupled with adoption have driven agriculture towards its development. Technological innovations act as a key vector for change in diverse disciplines (Ugochukwu and Phillips, 2018). The emerging technologies enhanced the development of food production and improve the quality and safety of food produced. The rate of technology adoption and the diffusion of same will determine the essential impact of the technology innovation. Research conducted over time reveals the nexus between technology adoption and diffusion processes and the factors affecting the adoption or the rejection of a technology by the end users (Stokey, 2023). In theory, it is assumed that the ultimate goal of generating new technology for adoption by farmers is to improve agricultural production and productivity. This is expected to enhance farming household welfare through increased income and consequently reducing poverty level. Nevertheless, real life experience shows that the potential effect of technology adoption is fully dependent on adoption status and the take up rate of such technology, (Zegeye, Fikire and Assefa, 2022). This reality is evidenced in a number of theories and models in adopting the technologies. Below are some of the theories and models applicable to the agricultural sector.

The Theory of Reasoned Action (TRA): This was developed in1975 by Fishbein and Ajzen (Kuo, Bau and Lowinger, 2015). It discusses factors influencing individual's behavior which includes the attitude which evaluate disposition to specific technology; social norms which deals with how others will feel about the same technology which will directly affect individual perception towards the technology and lastly, the outcome, that is, the individual decision to accept or not to accept the technology. TRA is commonly used in explaining human behavioral changes in field such as agriculture, health, education, and consumption behavioral studies.

Innovation-Decision Process Model: Rogers (1983) conceptualized the innovation-decision process with five stages speculated in the adoption process. These stages include the awareness of the new technology, secondly the persuasion to acquire more information about the innovation which can either be positive or negative. Thirdly is the decision to engage in activities which lead to a choice to adopt or reject the innovation, and fourthly is the implementation stage when the innovation has been put into practice. Finally, the confirmation stage is where the individual seeks reinforcements for the innovation decision made. However, this confirmation might not be permanent if individual is exposed to conflicting messages about the innovation.

Technology Acceptance Model (TAM): According to Dissanayake et al. (2022), this model was first speculated by Davis in 1985, and was developed for describing individual's behavior towards information technologies. The TAM explains the motivation of users by three factors namely perceived usefulness, perceived ease of use, and attitude toward use. However, this is considered as an advance development of the theory of reasoned action. The main concept of this model is based on the characteristics of the technology and acceptance of it.

Diffusion of Innovation (DOI) Theory: Taherdoost (2018) reported that the diffusion of innovation was developed by Rogers in 1995 and it describes individuals and organizational adoption behavior towards an innovation. The theory examined the diversity of innovations by introducing four factors namely; time, channels' communication, innovation or social system. It integrates major components such as adopter characteristics, innovation characteristics, and innovation decision process. The theory describes the stages an individual will enter before the adoption of a new technology. These stages include understanding, persuasion, decision, implementation, and confirmation, which provide the opportunity to group the adopters into five different categories namely: innovators, early adopters, early majority, late majority and laggards.

Expectancy Livelihood Model (ELM): Petersen and Pedersen (2010) as cited in Dissanayake (2022) introduced the ELM model which describes technology adoption and usage of the livelihood approach in livelihood development programs. ELM focused on the concepts of rural development and the vulnerability of dwellers with regards to where they live. The model emphasizes vulnerability level to risks, shocks, trends, and seasonal changes. The ELM focused on five capital sources available to individuals, and these are: social, human, natural, financial, and physical capitals. The capitals are used to evaluate the capital availability of the target population, and are also useful to form livelihood strategies in order to achieve the required livelihood outcomes in the society.

3. Materials and methods

3.1. The study area

This research was conducted in the North Central Region of Nigeria. As shown in **Figure 1**, the region comprises of Benue, Kogi, Kwara, Nasarawa, Niger, and Plateau States, and endowed with a land mass of about 296,898 km^2 with an estimated population size of about 20.36 million people. This study focused only on Kwara and Niger States due to prevalence of rice farming activities in these areas. The predominant livelihood activities in the region are agriculture and agricultural related activities with emphasis on food crop farming, but most farmers operate on smallholding farmlands (Food and Agriculture Organization (FAO), 2002; National Food Reserve Agency, 2008).

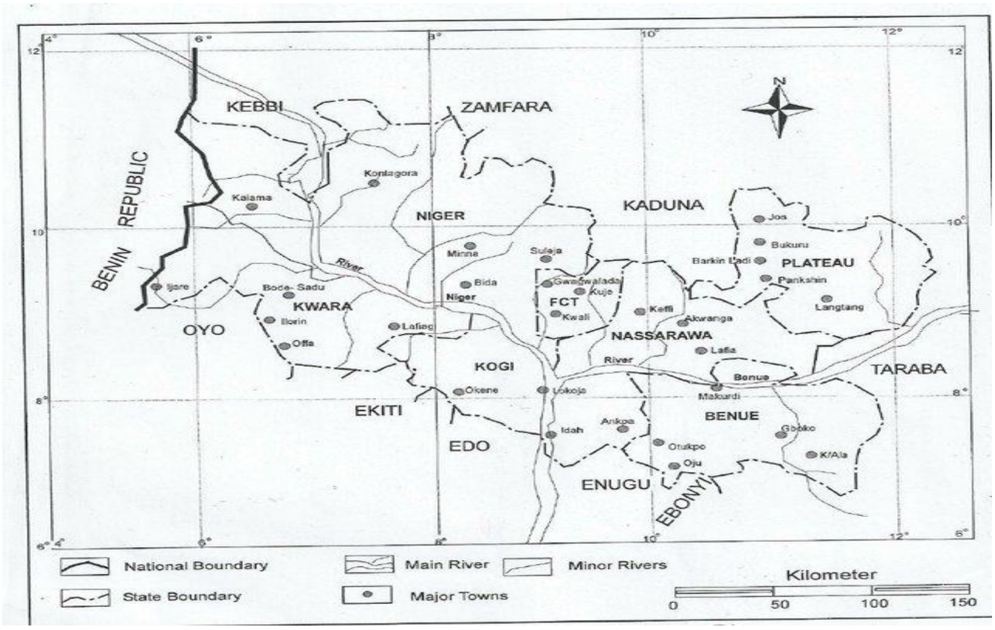

Figure 1. Map of selected north-central states, Nigeria.

Source: Oga, Eneji and Etim (2013).

3.2. Population of the study

The population of the study is made up of all the rice farmers, only in Kwara and Niger States of Nigeria.

3.3. Research design, sampling techniques and data collection

Cross-sectional study design was used for this study. In terms of sampling procedure, a multistage random sampling technique was used to select the respondents for this study. The first stage involved purposive selection of Kwara and Niger States, because these two States are reportedly among the top rice producing States in the region (Jirgi, Abdulrahman and Ibrahim, 2009; Abdullahi, 2012; Falola, Animashaun and Olorunfemi, 2014; Oloyede et al., 2020). Given the study area, there are four (4) Agricultural Development Programme (ADP) zones comprising of sixteen (16) Local Government Areas (LGAs) in Kwara state, while Niger State has three (3) ADP zones comprising of twenty five (25) LGAs.

In the second stage, two (2) LGAs (Edu and Pategi) and three (3) LGAs (Mokwa, Edati, Katcha) were purposively selected from Kwara and Niger States respectively, because of dominance of rice production in these LGAs, as observed in the list of rice producing LGAs obtained from the States' ministry of agriculture and rural development. The third stage involved the random proportionate to size selection of villages across the LGAs chosen in the second stage. In the last stage, the research made use of random proportionate sampling techniques for the selection of 400 hundred rice farmers who constitute the sample size for this study. But, 387 questionnaires were found useful for the final analyses.

Yamane's (1967) formula as cited in Otabor and Obahiagbon (2016) was used to determine the appropriate sample size. It is given as:

$$n = \frac{N}{1 + Ne^2} \tag{1}$$

where: n is the sample size for the study, N is the total population of the two states (Kwara and Niger), and e is the precision, which was set at ± 95%.

$$n = \frac{6993471}{1 + 6993471(0.05)^2} = 399.98 \approx 400$$

$$n = 400\ rice\ farmers$$

The sample size in each of the selected States, LGAs, villages are shown in the Appendix:

First Stage: There are two rice-producing LGAs in Kwara State, the two LGAs are selected. In Niger State, there are 7 major rice-producing LGAs; 4 LGAs were proportionally selected as follows: (2 out of 16 LGAs in Kwara State and x LGAs out of 25 in Niger State):

$$\frac{2}{16} = \frac{x}{25} = 3.125 \approx 3\ LGAs$$

The 3 LGAs that were determined to be selected were randomly selected from 7 major rice producing LGAs.

Second Stage: The number of villages was selected using the formula below:

$$B_i = \frac{A_i}{\sum A_i} \times 100$$

where:

$$B_i = \%\ of\ villages\ to\ be\ selected$$

$$A_i = Number\ of\ villages\ in\ LGAs$$

$$\sum A_i = sum\ total\ of\ number\ of\ villages\ in\ LGAs$$

Third Stage: The number of rice farmers in the villages was selected by using the formula:

$$C_i = \frac{B_i}{\sum B_i} \times 400$$

where:

$$C_i = number\ of\ farmers\ selected$$

$$B_i = \%\ of\ each\ villages\ selected$$

$$\sum B_i = sum\ of\ \%\ of\ each\ villages\ selected$$

However, the villages were combined into five or less enumeration areas (EAs) from which the required sample size was drawn (see Appendix).

In addition, the cross-sectional data which was used for this research was collected through the use of well-structured research instrument in line with the study objectives. Information was elicited on farmers' personal and socio-economic characteristics e.g., age, sex, household size, marital status, educational background etc.; inputs used in rice production, output of rice, use of improved rice varieties, and the problems the farmers encountered in their production season, amongst many other information. It is important to stress that farmers were given the opportunity to choose more than one rice varieties cultivated, if applicable.

3.4. Data analytical techniques

The study used a number of statistical techniques to describe and inferentially analyze the information elicited from the rice farmers in the study area. Following Battese and Coelli (1995), Mechri et al. (2017), as well as Abiola, Omhonlehin and

Sani (2021), Stochastic Frontier Production (SFP) model was applied to analyze the production efficiencies of the upland and lowland rice farmers in the study area. The reason for the use of SFP is because of its robustness strength to outliers and weaker assumptions about data distribution. Also, SFA produces two error terms. The first error term accounts for the technical efficiency and the second for factors such as measurement error in the output variable, and other unexpected events, as well as the combined effects of unobserved inputs. In line with Sirkin (1995), Yekinni (2007); Salimonu (2007) and Adepoju et al. (2011), composite score technique and descriptive analyses were also applied to profile the farmers into levels of adoption (low, moderate, and high) of improved rice varieties, while Multivariate regression model was used to estimate the effect of adoption of improved rice varieties on the production efficiencies of upland and lowland rice farmers in the study area.

4. Results and discussions

4.1. An array of the rice varieties adopted by farmers in the study area

The distribution of the various rice technologies available for adoption by rice farmers in the study area is presented in **Table 1**. The result showed the highest of percentage of both the upland (95.52%) and lowland (77.42%) rice farmers adopted Faro 44 rice variety, and this is followed by Faro 52 which accounted for 66.2% of upland and 56.45% of lowland rice farmers. The least adopted varieties include, Faro 46, Faro 48, Faro 53, Faro 59, Faro 61 and Faro 62 which has 6.97%, 4.98%, 3.48%, 8.46% and 5.47% respectively for upland rice farmers, while for the lowland rice farmers, 8.06%, 6.45%, 7.53%, 8.60%, 5.91% and 6.99% respectively are attributed to those varieties too. Meanwhile, the pooled result showed that only Faro 44 and Faro 52 were well adopted by both categories of rice farmers in the study area. The reason adduced for the farmers' preference of these two varieties is that they are more readily available, resistant to pest, diseases and drought, as well as good productivity output, compared to other varieties.

Table 1. Distribution of rice varieties adopted by farmers in North-Central, Nigeria.

Rice varieties	Upland*	Lowland*	Pooled*
Faro 44	192 (95.52)	144 (77.42)	336 (86.82)
Faro 46	14 (6.97)	15 (8.06)	29 (7.49)
Faro 48	10 (4.98)	12 (6.45)	22 (5.68)
Faro 52	133 (66.17)	105 (56.45)	238 (61.50)
Faro 53	7 (3.48)	14(7.53)	21 (5.43)
Faro 54	25 (12.44)	51 (27.42)	76 (19.64)
Faro 59	17 (8.46)	16 (8.60)	33 (8.53)
Faro 60	25 (12.44)	23 (12.37)	48 (12.40)
Faro 61	11 (5.47)	11 (5.91)	22 (5.68)
Faro 62	11 (5.47)	13 (6.99)	24 (6.20)

*Multiple response
Figure in parenthesis is percentage.
Source: Data analysis, 2023.

4.2. Production efficiencies of rice farmers and factors influencing farmers' efficiency

The technical, allocative and economic efficiency scores of the rice farmers is presented in **Table 2**. Among the upland rice farmers, about 52% of them operate under technical efficiency of 0.71 and 0.8 and 0.81to 0.9 for allocative efficiency. This accounted for the highest percentage while those with lowest percentage (3.48% and 1.49%) for technical and allocative efficiencies are farmers operating between 0.51 and 0.6 efficiency level. The economic efficiency results however revealed that upland rice farmers operating on efficiency level of 0.61–0.7 accounted for highest percentage (45.77%). Only 1% of them operate above this level, an indication that the upland rice farmers do not operate beyond 0.7 in their economic efficiency. It is noteworthy that none of the upland rice farmers operated beyond 0.9 efficiency level given the technical, allocative and economic efficiencies.

Furthermore, the lowland rice farmers' highest percentages for farmers operating at 0.71 to 0.8 efficiency level is 41.99% and 54.30% for technical and allocative efficiencies respectively. However, for economic efficiency, farmers operating at 50% or less accounted for percentage (44.62%) followed by farmers with efficiency level of 0.6 to 0.7 (36.56%). The result also showed that 0.54% of the lowland rice farmers operated beyond 0.9 efficiency level when compared with their counterpart, upland rice farmers. The pooled result further revealed both categories of farmers record highest percent of 47.29% and 44.44% for 0.7 to 0.8 efficiency level for technical and allocative efficiencies but record the lowest economic efficiency for this same level. In addition, none of the rice farmers operated at maximum production efficiency level.

Table 2. Distribution of technical, allocative and economic efficiencies of rice farmers in North-Central, Nigeria.

Efficiency	**Upland**			**Lowland**			**Pooled**		
Scores	**TE**	**AE**	**EE**	**TE**	**AE**	**EE**	**TE**	**AE**	**EE**
≤ 0.50	11 (5.47)	0 (0.00)	52 (25.87)	6 (3.22)	1 (0.54)	83 (44.62)	17 (4.39)	1 (0.26)	135 (34.88)
0.51–0.60	7 (3.48)	3 (1.49)	55 (27.36)	28 (15.05)	9 (4.84)	68 (36.56)	35 (9.04)	12 (3.10)	123 (31.78)
0.61–0.70	38 (18.91)	22 (10.95)	92 (45.77)	64 (34.41)	39 (20.97)	32 (17.20)	102 (26.36)	61 (15.76)	124 (32.04)
0.71–0.80	105 (52.24)	71 (35.32)	2 (1.00)	78 (41.94)	101 (54.30)	2 (1.08)	183 (47.29)	172 (44.44)	4 (1.03)
0.81–0.90	40 (19.90)	105 (52.24)	0 (0.00)	9 (4.84)	35 (18.82)	1 (0.54)	49 (12.66)	140 (36.18)	1 (0.26)
0.91–0.99	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.54)	1 (0.54)	0 (0.00)	1 (0.26)	1 (0.26)	0 (0.00)
1.00	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Total	201 (100.00)	201 (100.00)	201 (0.00)	186 (100.00)	186 (100.00)	186 (100.00)	387 (100.00)	387 (100.00)	387 (100.00)
Minimum	0.13	0.51	0.72	0.05	0.28	0.03	0.05	0.28	0.09
Maximum	0.86	0.85	0.09	0.91	0.91	0.83	0.91	0.91	0.72
Mean	0.72	0.78	0.56	0.68	0.74	0.50	0.70	0.76	0.54

Source: Data analysis, 2023.

4.3. Maximum likelihood estimates of stochastic production frontier for rice farmers

The maximum likelihood estimates of the parameters of stochastic production frontier model for the rice farmers are presented in **Table 3**. For the upland rice farmers, all parameters estimates except herbicide and labour had the expected positive signs and significant at 1% level which is an indication that these factors are significantly different from zero and are important inputs in rice production. Given the results, a unit increase in these variables will increase the output of upland rice farmers by 0.032, 0.026, 0.116 and 0.919 respectively. However, herbicide and labour had negative signs and are statistically significant at 1%, suggesting an indirect relationship with rice output. Hence, a unit increase in herbicide and labour will decrease rice output for upland rice farmers by 0.078 and 0.276 respectively.

On the other hand, while fertilizer and labour are statistically insignificant, other parameter estimates of the lowland rice farmers are positive and significant with the exception of farm size which is negative. The coefficients of seed, herbicide and capital were found to be positive and significant at 1%, 10% and 5% respectively thus having a direct relationship with rice output. This implies that a unit increase in the use of seed, herbicide and capital will lead to an increase in the output of lowland rice farmers by 0.118, 0.06 and 0.252 respectively. In term of farm size with indirect and significant (5%) relationship with rice output, the implication is that a unit increase in farm size will decrease the rice output of lowland rice farmers by 0.281.

Considering the pooled data, the coefficient of seed and capital were found to be positive and significant at 1%, thus having a direct relationship with rice output. Also, labour was found to be positive and significant at 10%. This implies that a unit increase in the use of seed, capital and labour will lead to an increase in rice output of farmers by 0.132, 0.282 and 0.128 respectively. Farm size indirectly affects rice output and significant at 1%, suggesting that a unit increase in the farm size will decrease the output of rice by 0.383. This is in line with the findings of Onyenweaku and Ohajianya (2005) where farm size, seed and labour were identified as significant factors affecting the production of rice farmers in Ebonyi state.

Furthermore, the estimates of the inefficiency model for the upland rice farmers revealed that age, household size, years of schooling, market distance, cooperative membership, association membership and weather station were significant factors affecting the inefficiency of upland rice farmers. Age, distance to market, and weather station have positive signs and are significant at 1%, 5% and 1% respectively. This implies that ageing, and increase in the distance to market and weather station will increase inefficiency of upland rice farmers by 5.49, 0.66 and 2.46, respectively. But, household size, year of schooling, cooperative membership and association membership were negative and significant at 1%, 5% and 10%, suggesting that increase in these variables will reduce the inefficiency (that is, boost efficiency) of upland rice farmers by 0.32, 0.06, 0.68 and 0.55, respectively.

Results of the inefficiency model for lowland rice farmers also indicated that market distance was positive and significant at 10%. This means that the farther the market distance, the more the farmers are inefficient and this is to the magnitude of 3.2. In addition, distance to home and research station were negatively significant at

5% and 10% respectively. An indication that a unit increase in these variables will reduce the inefficiency of lowland rice farmers by 2.13 and 3.76, respectively. This however is not in line with a priori expectation, because longer distances of farms to either homes or research stations results in inefficiency. Also, belonging to either cooperative societies or farmers' association renders the farmers efficient. This suggests that the more the farmers belong to cooperative societies and associations the less they become inefficient as observed in the results. This is expected because the farmers are incentivized in various ways and they also enjoy training and workshops that can make them improve on their farming activities.

Lastly, the pooled data results also revealed that age, distance to market and access to weather station were positively significant at 1%, 5% and 1% respectively. Intuitively, advancement in farmers' age, increase in the distance to market and weather station will increase the inefficiency of the rice farmers by 3.03, 0.79 and 0.02, respectively. Meanwhile, household size, distance to home, distance to research station, and access to weather station were negatively significant at 1%, 10% and 1% probability levels, respectively. The implication of the findings is that any increase in these variables will decrease the inefficiency of rice farmers by 0.14, 0.56, 0.001, and 1.47, respectively. The result is in tandem with the findings of Yaya et al. (2020), where some of these highlighted factors were also reported as contributory factors to the inefficiency of rice farmers.

Table 3. Maximum likelihood estimates of stochastic production frontier for rice farmers in North-Central, Nigeria.

	Upland			Lowland			Pooled		
Variables	**Coefficient**	**Std. Err**	**Z value**	**Coefficient**	**Std. Err.**	**Z value**	**Coefficient**	**Std. Err.**	**Z value**
Constant	−0.6993	0.0000	2.3×10^4***	3.6284	1.1200	3.24***	4.4428	1.1245	3.95***
Seed	0.0321	6.32×10^{-7}	5.1×10^4***	0.1178	0.0417	2.82***	0.1325	0.0381	3.47***
Herbicide	−0.0779	2.24×10^{-6}	3.5×10^4***	0.0600	0.0350	1.71*	−0.0507	0.0340	−1.49
Fertilizer	0.0264	2.08×10^{-6}	1.3×10^4***	−0.0635	0.0428	−1.49	0.0156	0.0428	0.36
Farm Size	0.1155	8.94×10^{-7}	1.3×10^5***	−0.2807	0.1393	−2.01**	−0.3830	0.0871	−4.40***
Labour	−0.2758	1.42×10^{-6}	-1.9×10^5***	0.1169	0.1047	1.12	0.1279	0.0751	1.70*
Capital	0.9192	3.21×10^{-6}	2.9×10^5***	0.2521	0.1013	2.49**	0.2827	0.1102	2.57***
Inefficiency model									
Constant	−12.677	2.0498	−6.18***	−33.1667	1204.95	−0.03	−1.2968	0.1516	−8.55***
Age	5.4900	0.5435	10.10***	−0.4770	2.0632	−0.23	3.0345	0.8527	3.56***
Household size	−0.3285	0.0300	−10.93***	0.1275	0.1137	1.12	−0.1460	0.0405	−3.6***
Year of schooling	−0.0668	−0.0668	−2.89***	0.0615	0.1008	0.61	0.0286	0.0311	0.92
Farming experience	−0.0218	0.0142	−1.53	0.0068	0.0529	0.13	−0.0083	−0.0083	−0.42
Distance to market	0.6667	0.3225	2.07**	3.2169	1.6753	1.92*	0.7992	0.3706	2.16**
Distance to home	−0.4802	0.2225	−2.16**	−2.1317	1.0034	−2.12**	−0.5683	0.3255	−1.75*
Membership of cooperative society	−0.6846	0.3433	−1.99**	−0.3119	1.0125	−0.31	−0.0848	0.3710	−0.23
Membership of farmers' association	−0.5548	0.3340	−1.66*	−0.4697	1.0287	−0.46	−0.3665	0.3713	−0.99
Access to research station	−4.0407	0.4468	−9.04***	−3.7689	1.9973	−1.89*	−1.4750	0.5069	−2.91***
Distance to research station	−0.0066	−0.0066	−1.55	−0.0006	0.0153	−0.04	−0.0077	−0.0077	−1.66*
Access to weather station	2.4689	0.4553	5.42***	33.5045	1204.9	0.03	2.0299	0.6051	3.35***
Distance to weather station	0.0099	0.0190	0.52	0.0144	0.0437	0.33	0.0162	0.0172	0.95
Sigma_square	1.22×10^{-9}	2.60×10^{-7}		0.6343	0.0359		0.5228	0.0396	

Source: Data analysis, 2023
*****- *p<0.1*; ******- *p<0.0*5%; ******* - *p<0.01*

4.4. Distribution of rice farmers by level of adoption of rice varieties

The distribution of respondents by level of adoption based on improved rice varieties adopted is shown in **Table 4**. The mean score of the adoption index was found to be 0.24 and the standard deviation was 0.20. Based on these values, the categorization of the farmers was made, and this process is shown as follows:

High category = between (0.24 + 0.20) points to 1 = 0.44 to 1.

Moderate category = between lower and upper categories = 0.04 to 0.44.

Low category = between 0 to (0.24 – 0.20) points = 0 to 0.04.

For the upland rice farmers, majority (90.05%) of the respondents were found to be intermediate adopters, while 9.45% and 0.50% were found to be high and low adopters. Furthermore, for the lowland rice farmers, 87.63% were found to be intermediate adopters while 10.75% and 1.61% were found to be high and low adopters respectively. In addition, for the pooled data most of the rice farmers were found to be intermediate adopters, while 10.08% and 1.03% were found to be high and low adopters respectively. The mean value of 0.24 implies that on the average, a rice farmer adopted at least two improved rice varieties in the study area.

Table 4. Distribution of rice farmers by level of adoption of improved rice varieties.

Level of	**Upland**		**Lowland**		**Pooled**	
Adoption	**Frequency**	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Low	1	0.50	3	1.61	4	1.03
Intermediate	181	90.05	163	87.63	344	88.89
High	19	9.45	20	10.75	39	10.08
Total	201	100.00	186	100.00	387	100.00

Source: Data analysis, 2023.

4.5. Effect of adoption of improved rice varieties on the efficiency of upland rice farmers in the study area

Table 5 presents the result of the multivariate regression model which captures the effect of adoption of improved rice varieties on the production efficiency of upland rice farmers in the study area. The three univariate models are empirically significant at p = 0.000, 0.000 and 0.0931 and R-square showed that all the predictors jointly explained 46.86%, 22.46% and 0.92% of the variance in the technical, economic and allocative efficiencies respectively. The technical efficiency model revealed that adoption rate ($p < 0.1$), distance to weather station ($p < 0.01$), farm size ($p < 0.01$), fertilizer ($p < 0.01$) and herbicide ($p < 0.01$) have statistically significant, and direct relationships with farmers' technical efficiency. This indicates that an increase in these variables will lead to an increase in technical efficiency of upland rice farmers by 0.035, 0.037, 0.74, 0.061, and 0.40 respectively. Also, distance to research station, and farm size under rice cultivation were negatively significant at 1%. The indirect relationships indicate that an increase in distance to research station and farm size will lead to increase in the technical efficiency of upland rice farmers.

Estimates from economic efficiency analysis revealed that adoption rate and years of schooling were positively significant, both at 5% probability level. This implies that a unit increase in adoption rate and years of schooling will increase economic efficiency of upland rice farmers, while distance to research station and market had inverse relationships with economic efficiency and significant at 1% and 5% probability levels, respectively. Hence, increase in these variables will lead to decrease in economic efficiency of upland rice farmers. Only seed and pesticide quantity negatively affect allocative efficiency at 10% significance level, while years of schooling positively influence allocative efficiency at 5% significance level. It is noteworthy that rice technology adoption rate positively influences technical efficiency at 1%, and economic efficiency at 5% significance level, but it has no significant effect on the allocative efficiency of upland rice farmers in the study area.

Table 5. Multivariate regression estimates of upland rice farmers in North-Central, Nigeria.

Variables	**Technical**			**Economic**			**Allocative**		
	Coef	**Std,Err**	***T*-Value**	**Coef**	**Std,Err**	***T*-Value**	**Coef**	**Std,Err**	***T*-Value**
Constant	0.6411	0.0614	10.43***	0.8062	0.0401	20.10***	0.9905	0.0302	32.82***
Adoption Rate	0.0352	0.0138	2.55***	0.0179	0.0090	1.99**	−0.0003	0.0068	−0.0400
Distance to research station	−0.0586	0.0069	−8.53***	−0.0158	0.0045	−3.53***	−0.0008	0.0034	−0.2500
Distance to weather station	0.0369	0.0142	2.60***	0.0084	0.0093	0.9100	−0.0004	0.0070	−0.0500
Farm size	0.0744	0.0149	5.00***	−0.0117	0.0097	−1.2000	−0.0119	0.0073	−1.6300
Rice Farm size	−0.0925	−0.0925	−5.18***	−0.0088	0.0117	0.7600	0.0130	0.0088	1.4800
Seed quantity	−0.0062	0.0077	−0.8100	0.0005	0.0050	0.1000	−0.0067	0.0038	−1.78*
Fertilizer quantity	0.0609	0.0169	3.61***	0.0083	0.0110	0.7500	−0.0036	0.0083	−0.4300
Herbicide quantity	0.0401	0.0121	3.31***	0.0069	0.0079	0.8700	0.0059	0.0060	0.9900
Pesticide quantity	0.0141	0.0120	1.1800	−0.0073	0.0078	−0.9300	−0.0107	0.0059	−1.82*
Distance to market	−0.0245	0.0157	−1.5600	−0.0227	0.0103	−2.21**	0.0040	0.0077	0.5100
Distance to home	−0.0004	0.0150	−0.0300	0.0082	0.0082	0.7110	0.0027	0.0074	0.3700
Years of schooling	0.0043	0.0136	0.3200	0.0175	0.0088	1.97**	0.0148	0.0067	2.22**
Equation	Obs	Parms	RMSE	R-sq	*F*-Value	*P*-Value			
Technical	201.00	13.00	0.0876	0.4686	13.8169	0.0000***			
Economic	201.00	13.00	0.0572	0.2246	4.5371	0.0000***			
Allocative	201.00	13.0000	0.0430	0.0093	1.6048	0.0931*			

Obs—observation, Parms—parameters, RMSE—root mean square error, *R*-sq—*R*-squared,
F-values—*F*-statistics, *P*-values—*P*-statistics,
***** - $p<0.1$; ****** - $p<0.05$%; ******* - $p<0.01$
Source: Data analysis, 2023.

4.6. Effect of adoption of improved rice varieties on the efficiency of lowland rice farmers

Table 6 presents the result of the multivariate regression which captures the effect of adoption of improved rice varieties on production efficiency of lowland rice farmers. The three univariate models are empirically significant at p = 0.000, 0.000 and 0.0931 and the R-square showed that all the predictors jointly explained 46.86%, 22.46% and 0.92% of the variance in the technical, economic and allocative respectively. The technical efficiency results revealed that adoption rate and farm size were found positive and significant at 10% and 5% respectively. This indicates that increase in rate of adoption and farm size will lead to increase in the technical efficiency of lowland rice farmers by 0.30 and 0.05, while distance to weather station and market were negatively significant at 1%. An indication that distance to weather station and market indirect affect technical efficiency, hence, increase in these variables will decrease technical efficiency of lowland rice farmers by 0.03, and 0.05.

In addition, the economic efficiency result reveals that farm size and herbicide quantity were positively significant at 1% and 10% respectively. This indicates that an increase in these will increase the economic efficiency of lowland rice farmers by 0.04 and 0.008. Also, distance to weather ($p < 0.01$) and market ($p < 0.01$) had indirect relationship with economic efficiency. Lastly, allocative efficiency results showed that farm size was positively significant at 1%, therefore, increase in farm size will lead to increase in the allocative efficiency of lowland rice farmers by 0.35. Rice technology adoption rate had indirect relationship with allocative efficiency, which implies that a unit increase in adoption rate by lowland rice farmers will lead to a decrease in their allocative efficiency. However, adoption rate has no significant effect on the economic efficiency of lowland rice farmers.

Table 6. Multivariate regression estimates of lowland rice farmers in North-Central, Nigeria.

Variables	**Technical**			**Economic**			**Allocative**		
	Coef	**Std,Err**	***T*-Value**	**Coef**	**Std,Err**	***T*-Value**	**Coef**	**Std,Err**	***T*-Value**
Constant	0.7372	0.0609	12.10***	0.7878	0.0407	19.37***	0.9767	0.0238	40.96***
Adoption Rate	0.0302	0.0157	1.92*	0.0045	0.0105	0.4300	−0.0136	0.0062	−2.20**
Distance to research	0.0044	0.0084	0.5200	−0.0013	0.0056	−0.2300	0.0003	0.0033	0.0800
Distance to weather station	−0.0313	0.0113	−2.77***	−0.0198	0.0075	−2.63***	−0.0022	0.0044	−0.5100
Farm size	0.0543	0.0239	2.27**	−0.0142	0.0160	−0.8900	−0.0125	0.0094	1.3300
Rice Farm size	−0.0327	0.0220	−1.4800	0.0406	0.0147	2.76***	0.0349	0.0086	4.04***
Seed quantity	0.0031	0.0079	0.3900	0.0083	0.0053	1.5700	0.0001	0.0031	0.0400
Fertilizer quantity	0.0017	0.0071	0.2400	0.0013	0.0048	0.2800	−0.0009	0.0028	−0.3200
Herbicide quantity	0.0048	0.0071	0.6800	0.0080	0.0048	1.68*	0.0012	0.0028	0.4400
Pesticide quantity	−0.0040	0.0062	−0.6400	−0.0039	0.0041	−0.9400	−0.0003	0.0024	−0.1400
Distance to market	−0.0523	0.0200	−2.62***	0.0312	0.0134	−2.34**	0.0012	0.0078	0.1500
Distance to home	0.0304	0.0187	1.6300	0.0027	0.0125	−0.2200	−0.0113	0.0073	−1.5400
Years of schooling	0.0016	0.0175	0.0900	0.0015	0.0117	0.1300	0.0012	0.0069	0.1800
Equation	Obs	Parms	RMSE	*R*-sq	*F*-values	*P*-values			
Technical	186	13	0.1112	0.1627	2.8009	0.0016**			
Economic	186	13	0.0743	0.2119	3.8766	0.0000***			
Allocative	186	13	0.0435	0.1379	2.3070	0.0094**			

Obs—observation, Parms—parameters, RMSE—root mean square error, *R*-sq—*R*-squared,
F-values—*F*-statistics, *P*-values—*P*-statistics,
***** - $p<0.1$; ****** - $p<0.05$%; ******* - $p<0.01$
Source: Data analysis, 2023.

4.7. Effect of adoption of improved rice varieties on the efficiency of rice farmers (pooled) in the north-central, Nigeria

Table 7 presents the result of the multivariate regression which captured the effect of adoption of improved rice varieties on the production efficiency of all the rice farmers. As noted earlier, Faro 44 and Faro 52 rice varieties were well adopted by both groups of rice farmers in the study areas because these varieties are more readily available, resistant to pest, diseases and drought, as well as for their good productivity output, compared to other varieties. Therefore, the three univariate models in respect of the adoption effect of improved rice varieties on the efficiency of the rice farmers are empirically significant at p = 0.000, 0.000 and 0.0283, respectively, while the R-square showed that all the predictors jointly explained 18.3%, 17.9% and 5.9% of the variance in the technical, economic and allocative respectively. In the Technical Efficiency model, result revealed that the adoption rate, land size and distance to home were positively significant at 5%, 1% and 10% significant levels. This implies that a unit change in these variables will lead to increase in technical efficiency of rice farmers by 0.026, 0.0057 and 0.0235 respectively. Also, distance to research station, rice farm size and distance to market were negatively significant at 1%, and 10%, a unit increase in these variables will reduce the efficiency of the rice farmers by 0.005, 2394, 0.073 respectively. This is against the a-prior expectation for rice farm size.

The economic efficiency result revealed that adoption rate, rice farm size and quantity of herbicide positively affect economic efficiency at 10%, and 5% significant levels. This implies that a unit change in these variables lead to equivalent change in economic efficiency of rice farmers by 0.0123, 0.0130 and 0.0079. In addition, distance to research station and market had an indirect relationship with economic efficiency and both are significant at 1%. This implies that an increase in the distance to research and market will decrease the economic efficiency of rice farmers by 0.012 and 0.041. The allocative efficiency result showed that only rice farm size and years of schooling were positive and significant at 1% and 10% respectively. This indicates that an increase in the size of rice farm and years of schooling will increase the allocative efficiency of rice farmers by 0.019 and 0.0087 respectively.

Table 7. Multivariate regression estimates of rice farmers in North-Central, Nigeria (pooled).

Variables	Technical Efficiency			Economic Efficiency			Allocative Efficiency		
	coef.	**std. error**	***t*-value**	**coef.**	**std. error**	***t*-value**	**coef.**	**std. error**	***t*-value**
Constant	0.8157	0.0434	18.81***	0.8186	0.0272	30.13***	0.9734	0.0173	56.20***
Adoption Rate	0.0263	0.0109	2.41**	0.0122	0.0068	1.79*	−0.0005	0.0044	−1.1600
Distance to research	−0.0314	0.0056	−5.61***	−0.0127	0.0035	−3.61***	−0.0008	−0.0008	−0.3500
Distance to weather station	0.0052	0.0081	0.6400	0.0002	0.0051	0.0500	−0.0005	0.0032	−0.1700
Farm size	0.0573	0.0138	4.16***	−0.0115	0.0086	−1.3300	−0.0071	0.0055	1.2900
Rice Farm size	−23945.00	0.0136	−1.76*	0.0130	0.0085	1.92*	0.0196	0.0054	3.61***
Seed quantity	−1128.000	0.0058	−0.2000	0.0048	0.0036	1.3500	−0.0034	0.0023	−1.4900
Fertilizer quantity	−0.0034	0.0064	−0.5400	−0.0018	0.0040	−0.4400	−0.0020	0.0025	−0.7900
Herbicide quantity	0.0099	0.0062	1.6000	0.0080	0.0039	2.05**	0.0024	0.0025	0.9700
Pesticide quantity	−0.0065	0.0055	−1.1700	−0.0054	0.0035	−1.5600	−0.0025	0.0022	−1.1500
Distance to market	−0.0734	0.0126	−5.84***	−0.0408	0.0079	−5.18***	0.0050	0.0050	1.0000
Distance to home	0.0235	0.0127	1.85*	0.0066	0.0080	0.8300	−0.0052	0.0051	−1.0200
Years of schooling	0.0093	0.0120	0.7700	0.0123	0.0075	1.6400	0.0088	0.0048	1.84*
Equation	Observation	Parameters	RMSE	R^2	*F*-Value	*P*-Values			
Technical	387	13	0.1099	0.1826	6.9603	0.0000***			
Economic	387	13	0.0688	0.1785	6.7742	0.0000***			
Allocative	387	13	0.0439	0.0587	1.9440	0.0283**			

coef.—Coefficient.
***** - $p<0.1$; ****** - $p<0.05$%; ******* - $p<0.01$
Source: Data analysis, 2023.

5. Conclusion and recommendations

Based on the findings, majority of the rice farmers are technically efficient; however, these farmers operate mostly between 70% and 80% level, while their economic efficiency is on the average level, that between 50% and 60%. Estimates of the stochastic model established that seed, herbicide, fertilizer, farm size and capital affect the efficiency of upland rice farmers, while seed, farm size capital and herbicide affect the efficiency of the lowland counterparts. Also, adoption rate for farmers on both count influences the technical and economic efficiency, but it has no effect on the allocative efficiency. To address the specific challenges and opportunities identified in the research which can contribute to improving rice production efficiency among the upland and lowland rice farmers, and enhancing food security in the study area, and Nigeria, the following policy recommendations are put forward:

- Promotion of adoption of improved rice varieties: Government and development experts should develop and implement policies and programs aimed at encouraging farmers to scale up the adoption of improved rice varieties like Faro-46 and Faro-52, which were found to be popular among rice farmers. This can be achieved through provision of subsidies or incentives for farmers to access and use these improved varieties, which could include discounts on seeds and training on their cultivation.
- Investment in agricultural research and extension services: Allocate resources to agricultural research and extension services to continuously develop and promote new and improved rice varieties. This can be achieved through the establishment of demonstration farms to showcase the benefits of adopting these varieties, and provide farmers with the necessary knowledge and skills to effectively cultivate them.
- Seamless access to agricultural inputs: Government and development experts should ensure reliable and affordable access to essential agricultural inputs such as seeds, herbicides, and fertilizers, as these were found to influence production efficiency. This can be achieved by implementation of policies that reduce the cost of these inputs for farmers, possibly through subsidies or bulk procurement.
- Prioritization and support for smallholder farmers: Focus should be placed on assisting the smallholder rice farmers, particularly those in the upland areas, to improve their efficiency. This can be achieved through facilitation of credit access and financing options using their various registered cooperation societies. This will enable smallholders to invest in capital assets and increase their farm size.
- Development of continuous capacity building programs: Government and development experts should develop and implement programs to enhance the technical and economic efficiency of rice farmers. This might involve training in modern farming techniques, pest and disease management, and post-harvest handling. Similarly, provision of access to mechanization and modern farming equipment to improve farm operations and reduce labor-intensive practices can be very helpful. In the same vein, while most farmers in the study were technically efficient, their allocative efficiency was suboptimal. Conduct outreach and training programs to help farmers make informed decisions regarding resource allocation.

- Promotion of market access and value addition: The need to improve market access for rice farmers is sacrosanct. This can be achieved through investment in infrastructure and transportation networks. Encouraging value addition through processing and packaging to increase the income potential for farmers and reduce post-harvest losses can promote the food security drive of the government.
- Lastly, there is a need to prioritize data collection, monitoring and evaluation of adoption process. This can be achieved by putting in place a robust data collection and monitoring system to track the adoption rates of improved rice varieties, and the efficiency levels of farmers. This data and information can be used to continuously assess the impact of policies and programs, and making adjustments from time to time, as necessary.

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Appendix

Table A1. Sample size distribution in Kwara and Niger States of Nigeria.

States	**Numbers of LGA**	**Selected LGA**	**Number of Villages in LGAs (A*i*)**	**% of villages selected (B*i*) =** $A_i / \sum A_i \; X\ 100$	**Number of farmers selected** $C_i = B_i / \sum B_I \; X\ 100$
Kwara	16	Edu	167	25.54 = 43	102
		Pategi	70	10.70 = 7	43
Niger	25	Mokwa	66	10.09 = 7	40
		Edati	149	22.78 = 34	91
		Katcha	202	30.89 = 62	124
Total			654	100	400

Source: authors' computation.