Impact of adoption of mobile-based Information Communication Technologies on production efficiencies among smallholder farmers in the southwest of Nigeria

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The objective of this study was to assess differences in production efficiencies and identify factors that affect efficiencies and inefficiencies of adopters and non-adopters of mobile-based Information Communication Technologies (ICTs) among cassava farming households in the southwest of Nigeria. Primary data were collected using a structured questionnaire from a sample of 216 cassava farmers (104 adopters and 112 non-adopters) non-randomly selected through snowballing from Oyo and Ogun States during the 2020/2021 production season. Descriptive statistics were calculated and the Production Frontier model was used to estimate technical (TE), allocative (AE) and economic efficiency (EE) of adopters and non-adopters as well as factors influencing production inefficiencies. The results indicated that adopters had mean TE, AE and EE of 75.1, 30.7 and 23.1% respectively compared with non-adopters who had mean TE, AE and EE of 27.9, 85.1 and 78.3% respectively. Therefore, there are differences between the efficiencies of adopters and non-adopters of mobile-based ICTs. Factors driving cassava production efficiencies include farm size, labour used, stem cuts, fertiliser and agrochemical use, level of formal education, number of mobile-based ICTs used, access to extension services and access to credit. To address production inefficiencies of cassava, efforts should be focused on improvement of existing farm resources, sensitisation of farmers on the need to adopt mobile-based ICTs, strengthening of the agricultural extension system, access to credit and investment in the basic education of small scale farmers.

Keywords: Mobile apps, stochastic frontier analysis, data envelopment analysis, smartphone, inefficiencies

Worldwide production of cassava was about 278 million metric tons in 2018, out of which Africa's share was about 61% (FAOSTAT 2020). Nigeria accounts for cassava output of up to about 60 million metric tons (20%) of world total production. The country produces about 34% of the production from Africa and 46% of production from West Africa countries.

Cassava is an important root crop in Nigeria and the most widely cultivated crop in the southern part of the country both in the of area devoted to it and number of farmers growing it (Ogunniyi et al. 2012). The cassava value chain however, is plagued with problems of inefficiency in production, due to a number of factors including low resources productivity, profitability, under-capitalisation, inefficient use of farm-based inputs (Sanusi 2012), small scale size of farming (Bamidele et al. 2008; Ojimba 2017), manual operations, little or no usage of fertilisers and other chemicals and limited knowledge of improved technologies (Ojimba 2017). One way to effectively address issues of low agricultural productivity and production efficiency is the use of Information and Communication Technology (ICT). Use of mobile phone applications by farmers (Krell et al. 2020; Mandi and Patnaik 2019; Sharma et al. 2020) could increase adoption of modern industrial inputs in agricultural production as they rely on information and communication infrastructure (Lio and Liu 2006).

Mobile technology is any device that has connectivity to the internet and may be used anywhere. Mobile-based ICTs, such as telephone apps and social media have become important tools in promoting agricultural value chain efficiency (Kiambi 2018). Recent

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statistics showed that 62.9% of the population worldwide owned a mobile phone with 4.68 billion users on the planet (Statista 2019). Mobile phones are in the vanguard of ICTs in agriculture (Abdulsalam et al. 2016). The cellular phone has empowered the farmers to communicate from local to administrative levels regarding agricultural trade, information exchange and buying and selling inputs and farm commodities (Ogutu et al. 2014). This has reduced the need and cost of traveling and improved the production efficiency of farming communities living in remote areas (Aker and Mbiti, 2010, Rahman et al. 2020). Applications of mobile-based ICTs can support farmers directly through SMS messages. ICTs today play an integral role directly or indirectly in agricultural and rural development by improving productivity, enhancing food security, and improving farmers' livelihoods and general welfare (Sekabira and Qaim 2017). Use of mobile-based ICTs can contribute to efficiency and sustainable agricultural production by providing dynamic, reciprocal and effective information exchange regarding agriculture-enabling innovations (El Bilali and Allahyari 2018; Klerkx et al. 2019; Munthali et al. 2018; Zhang et al. 2016). Use of ICTs to access information may affect the production of crops because farmers may change their production choices by combining and using different inputs (e.g., labour, capital assets, fertilisers and pesticides). The use of ICTs in agriculture provides a more efficient and cost-effective way of sharing and exchanging knowledge more widely (Khan et al. 2022).

The objective of this study was to assess the impact of adoption of mobile-based ICTs on the production efficiencies among smallholder farmers in southwest Nigeria. The specific objectives were two-fold: first, to estimate cassava current level of technical, allocative and economic efficiencies differentials between adopters and non-adopters; second, to identify factors influencing any inefficiencies.

Motivating reasons for the study

One of the major objectives in farming is not only to boost output but also to improve efficiency (Yekti et al. 2015) and eliminate the constraints on the adoption of new technology (Obwona 2006). This study assessed the influence of mobile-ICTs on agricultural production efficiency on sustainable development in the agricultural sector, with the view to determining whether the adopters of such innovations are more efficient than non-adopters (those who do not use ICTs to access farm information). There is still a dearth of information available on the impact of adoption of mobile-based ICTs on production efficiency among the smallholder cassava farmers in the country, as the use of mobile telephones to facilitate communications, social interactions and improve farmer skills and knowledge is expanding. This study aimed to fill this gap by providing empirical evidence on the impact of adoption of mobile-based ICTs on production efficiencies among the cassava smallholder farmers in southwest Nigeria. The findings will contribute to the body of knowledge concerning adoption of mobile-based ICT tools. Understanding the levels of production efficiencies and the roles played by mobile-based ICTs contributes to the identification of production constraints at farm level and thereby improves food security and income sources in the farm sector and the rest of the economy. Furthermore, such knowledge may help policy-makers to design appropriate policies to increase cassava production efficiency among small-scale value chain operators.

Theoretical and brief literature review

Production efficiency is built on the microeconomics notion of the production function, which transforms input into output. Evidence from literature shows that there have been concerted efforts (Coelli et al. 2002; Greene 2007; Okoruwa et al. 2009; Aboki et al. 2013; Ademiluyi et al. 2013; Girei et al. 2014; Igbaifua et al. 2021) at investigating production efficiency of cassava farmers. Most of these studies show a common understanding and definition of production efficiency. Production efficiency is a measurable concept that can be determined by determining the ratio of useful output to total input. Efficiency is an effort to utilise minimum input in order to gain maximum output. Measuring production efficiency is essential because it is the first step in the process leading to substantial resource saving which has very important implications in policy formulation and farm management (Bravo-Ureta and Rieger 1991). For the distribution of inputs and improvement of farming managerial abilities, understanding the quantity and distribution of efficiency has a big impact. Technical efficiency is a combination of capacity and ability of economic units to produce the maximum output from a number of inputs and technologies. A farmer is technically said to be more efficient than others when the utilisation of the same type and number of inputs obtained higher physical output (Lau and Yotopoulos 1971), allocative efficient if he/she is producing the maximum possible output at minimum cost.

Kelemu (2016) found a significant impact of mobile phones and mobile communications on improving wheat productivity and efficiency in Ethiopia. In addition, Quandt et al. (2020) examined perceptions about the effects of mobile phone use on agricultural productivity in rural Tanzania, East Africa. They reported that 47% of respondents stated that mobile phone usage had reduced the amount of time they spent buying inputs or selling crops, and 50% reported that mobile phone usage had reduced the amount of money they spent on farm activities. Further, 64% reported that mobile phone usage had increased profits from farming compared to when the respondent did not have a mobile phone. Mwalupaso et al. (2019) studied the impact of mobile phone access to information technology on corn production in Zambia. They observed that mobile phones have greatly improved the technical efficiency of farmers.

Materials and methods

Description of the study area

Crop production along with livestock rearing is the main economic activity of farmers in the study area. Root and tuber crops constitute the majority of crop production followed by cereals, fruit crops, oilseeds, pulses, vegetables and spices. The major root and tuber crops cultivated are cassava and yam.

Sources of data and sampling techniques

This paper is based on cross-sectional data from 216 Cassava producers in Oyo and Ogun States, southwest, Nigeria. Because of the non-availability of the population size of adopters (farmers that use any mobile-based ICTs for production purposes in terms of communication on sources of inputs, making payments, improvement of skills and knowledge especially with the introduction of specialised mobile-based apps for fertiliser application, seed tracking etc.) and non-adopters in the study area. Respondents were selected through a non-random technique (snowballing). Trained interviewers used a pre-tested semi-structured questionnaire to collect the data. Also, focus group discussions were held to complement the data collected through the questionnaire.

Methods of data analysis

There are two common approaches of measuring production efficiency, namely Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). Both techniques analyse data using distinct approaches, taking into consideration random noise and flexibility in the structure of technology of production. Due to these variations, choosing between the parametric SFA and the non-parametric DEA methods has been an issue of debate. Nevertheless, studies carried out on efficiency measurement indicate that a researcher can use any of these methodologies because the estimated results are not significantly different (Coelli et al. 2002; Haji 2006). The DEA (programming approach) however (Farrell 1957) requires one to construct a free disposal convex hull (maximum possible output) in the input-output space from a given sample of observations of inputs and outputs. This approach is weak, because the maximum possible output is derived using only marginal data rather than all the observations in the sample making the estimated efficiency susceptible to outliers and measurement errors (Forsund et al. 1980). The approach also has very demanding data needs and being non-parametric, no statistical inferences on the estimates can be carried out.

This study used the SFA (Battese and Coelli 1995) to estimate the production efficiency and analyse the determinants of inefficiency of the respondents. The main advantage of SFA is that it takes into account stochastic variation of the output due to its ability to account for random noise that can affect output. The stochastic frontier parameters are statistically testable, as their confidence levels and the accuracy of the estimated models are known. This model simultaneously estimates both technical efficiency scores and identify factors affecting the level of a firm's inefficiency. On the other hand, the SFA model is limited to the production of single output and the need to assume a functional form for the frontier technology and for the distribution of technical inefficiency term of the composite error term (Ahmadzai 2017).

The Stochastic Production Frontier model was used to examine the production efficiency:

$$Ln(Y) = \beta_0 + \beta_1 Ln(X_1) + \beta_2 Ln(X_2) + \beta_3 Ln(X_3) + \beta_4 Ln(X_4) + \beta_5 Ln(X_5) + \varepsilon_i$$

Where:
Y = cassava output (kg/ha),
X_1 = farm size (ha);
X_2 = labour (person days/ha);
X_3 = fertiliser (kg/ha);
X_4 = agrochemical (L/ha);
X_5 = cassava stem cuttings (kg/ha);
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ = coefficients of inputs (X_1 ------X_5) with respect to output level.
ε_i is the composed error term where $\varepsilon_i = V_i - U_i$ with $U_i \geq 0$. The random error V_i accounts for the stochastic effects beyond the producer's control, measurement errors as well as other statistical noise, and U_i captures production inefficiency due to factors that are in the control of the producer.

The corresponding cost frontier of the Cobb-Douglas functional form was used as the basis of estimating the allocative efficiencies of the cassava farmers in the study area:

$$Ln(C) = \propto_0 + \propto_1 Ln(P_1) + \propto_2 Ln(P_2) + \propto_3 Ln(P_3) + \propto_4 Ln(P_4) + \propto_5 Ln(P_5) + \propto_6 Ln(P_6) + \varepsilon_i$$

Where:

C = total cost of production (₦);
P_1 = cost of fertiliser (₦);
P_2 =cost of labour (₦);
P_3 = cost of cassava setts (₦);
P_4 = cost of chemicals (₦);
P_5 = cost of farm implements use (₦);
P_6= other operating expenses; cost of transport, sacks and packaging (₦).

Economic Efficiency was calculated based on Farrell's methodology as the product of Allocative Efficiency (AE) and Technical Efficiency (EE). That is, EE = TE * AE.

The technical /allocative inefficiency model is defined as:

$$U_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \delta_8 Z_8$$

Where:

U_i = technical /allocative inefficiency,
Z_1 = Age of the farmer (years)
Z_2 = farming experience (years)
Z_3 = level of education (years);
Z_4 = household size (number);
Z_5 = access to extension services (yes = 1, no = 0);
Z_6 = Sex (Female = 1 otherwise = 0);
Z_7 = number of mobile-based ICTs used (number);
Z_8 = access to credit (yes = 1, no = 0); δ_0, δ_1, δ_2, δ_3, δ_4, δ_5, δ_6, δ_7, δ_8 are the parameters to be estimated.

U_i the dependent variable is defined in terms of technical inefficiency; a farm-specific variable associated with the negative coefficient will have a positive impact on technical efficiency, and vice versa (Ahmadzai 2017; Baruwa et al. 2018).

Results

Descriptive statistics of socioeconomic characteristics and production variables of cassava farmers

The socioeconomic characteristics of cassava farmers and production function variables are shown in Table 1. The mean ages of adopters and non-adopters of mobile-based ICTs among cassava producers were 48.3 and 49.4 years respectively. The mean years of experience by adopters and non-adopters were 24.9 and 24.6 respectively, while the mean land area allocated to cassava production (owned shared and rented land) by household was 4.4 for adopters and 3.4 ha for non-adopters.

The mean quantity of cassava cuttings that adopters used per ha was 56.5 bundles against 48.0 bundles by the non-adopters. Mean labour used per hectare was 58 persons for adopters and 53 persons for non-adopters. The mean number of mobile-based ICTs by adopter households was 1.4. The average cassava yields of 10.5 and 9.2 t/ha by adopters and non-adopters respectively are low when compared to the potential values 20 - 25 t/ha if recommended varieties and management practices are carried out in Nigeria (Foundation for Partnership Initiatives in the Niger Delta 2011).

Table 1: Descriptive statistics of some socioeconomics characteristics of the respondents and production variables

Variables	**Adopters (n=104)**		**Non-adopters (n=112)**	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**
Age	48.3	10.2	49.4	12.6
Household size	7.0	3.0	7.0	3.0
Years of farming experience	24.9	11.4	24.6	10.9
Years of schooling	6.2	4.2	4.0	3.9
Number of mobile based ICTs	1.4	0.9	0	0
Farm size (ha)	4.4	1.7	3.4	2.7
Stem cuttings (bundles/ha)	56.5	12.7	48.0	5.2
Labour (person/ha)	58.0	3.2	53.0	3.0
Agrochemical (L/ha)	1.1	0.9	0.9	0.3
Fertiliser (kg/ha)	129.1	3.0	118.1	20.5
Output (t/ha)	10.5	1.8	9.2	1.9

Estimation of production efficiencies and their determinants

Table 2 presents the estimated parameters of the Stochastic Production Frontier model. A stochastic frontier estimate and significance of the sigma-square (σ^2) at 1% level implies good fit and justifies the assumptions of the distribution of the composite error term. The estimated log likelihood function of -125.717 and -184.800 for adopters and non-adopters in TE, -249.767 and -184.800 for adopters and non-adopters in AE represent the values that maximise the joint densities in the estimated model. The gamma (γ) values of 83.2% (adopters) and 64.2% (non-adopters) in TE showed that 83.2% and 64.2% of the variation in output of cassava by adopters and non-adopters were caused by technical inefficiency. Similarly, in the AE model, the gamma value of 0.571 (adopters) and 0.642 (non-adopters) implied that 57.1% and 64.2% of the random variation in the adopter and non-adopter models were due to allocative inefficiency.

TE and AE of cassava production by both adopters and non-adopters of mobile-based ICTs were positively and significantly influenced by farm size. Farm size had a positive relation with TE and AE at the 1% level of significance. This suggests that farmers with large farm size have the money, education and technical expertise that could increase efficiency. The costs of purchasing land and cassava stems had positive coefficients and significantly ($P \leq 0.01$) influenced AE.

The results of the efficiency scores (Table 3) show that the mean TE level for the adopters was 0.751 (75.1%) and TE indices varied from minimum of 0.017 to a maximum value of one, while the mean TE level for the non-adopters was 0.279 (27.9%) with a minimum score of 0.003 and maximum of 0.999. These show that cassava farmers who adopted mobile-based ICTs in the study area are more technically efficient than the non-adopters.

Mean AE level of adopters was 0.307 (30.7%) with a minimum AE of 0.017 and maximum value of 0.999, while the non-adopter had mean AE of 0.851 (85.1%) with minimum value of 0.073 and maximum value of 0.981 indicating high levels of inefficiency in resource allocation. The combined effect of TE and AE showed that the mean EE level for adopters was 0.231 (23%), with a minimum of 0.017 and maximum of 0.999, while for non-adopters, the mean EE was 0.783 (78%) with a minimum of 0.073 and maximum of 0.981.

Table 2: Maximum likelihood estimates of the Stochastic Production Frontier function of cassava producers

	Technical efficiency				**Allocative efficiency**				
Variables	**Adopters**		**Non-adopters**		**Variables**	**Adopters**		**Non-adopters**	
Output	Coefficient	P	Coefficient	P	**Total cost**	Coefficient	P	Coefficient	P
Farm size	0.638^{***} (0.106)	0.001	0.709^{***} (0.135)	0.001	Cost of farm land	0.143^{***} (0.005)	0.001	0.401^{***} (0.085)	0.001
Labour	0.332^{***} (0.111)	0.003	-0.054 (0.035)	0.117	Cost of labour	0.036 (0.031)	0.244	0.087 (0.113)	0.437
Fertiliser	0.160^{***} (0.041)	0.001	-0.072 (0.046)	0.118	Cost of fertiliser	0.018 (0.048)	0.703	-0.005 (0.047)	0.920
Agrochemicals	0.214^{**} (0.085)	0.011	-0.306^{***} (0.002)	0.001	Cost of agrochemicals	0.089 (0.057)	0.120	0.152 (0.101)	0.132
Cassava stems cuttings	-0.065 (0.072)	0.368	-0.223 (0.136)	0.100	Cost of cassava stems cuttings	0.152^{***} (0.019)	<0.001	0.902^{***} (0.095)	0.001
Constant	10.461^{***} (0.272)	0.001	12.197^{***} (0.437)	0.001	Constant	11.224^{***} (0.334)	0.001	2.441 (3.230)	0.450
Diagnosis statistics									
Sigma-square	0.7318^{***} (0.168)		0.420^{***} (0.156)		Sigma-square	5.065^{***} (0.687)		0.420^{***} (0.154)	
Gamma	0.832 (0.395)		0.642 (0.217)		Gamma	0.571 (0.187)		0.642 (0.217)	
Number of observations	104		112		Number of observations	104		112	
Wald chi^2(5)	182.54		1.69e+09		Wald chi^2(5)	843.69		1.69e+09	
Log likelihood	-125.717		-184.800		Log likelihood	-249.767		-184.800	
Prob > chi^2	0.001		0.001		Prob > chi^2	0.001		0.001	

Values in parentheses are the standard errors, ** and *** significance at 5 and 1% respectively

Table 3: Distribution of the TE, AE and EE scores by adopters and non-adopters of mobile-based ICTs

	Adopters						Non-Adopters					
Efficiency scores	**TE**		**AE**		**EE**		**TE**		**AE**		**EE**	
	Number	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
< 0.5	17	16.35	80	76.92	89	85.58	95	84.82	11	9.82	15	13.39
0.5 - 0.69	29	27.88	14	13.46	10	9.62	8	7.14	12	10.72	20	17.86
0.7 - 0.89	12	11.54	4	3.85	3	2.88	3	2.68	19	16.96	13	11.61
0.9 - 1.00	46	44.23	6	5.77	2	1.92	6	5.36	70	62.50	64	57.14
Total	104	100	104	100	104	100	112	100	112	100	112	100
Minimum	0.017		0.017		0.017		0.003		0.073		0.073	
Maximum	1.000		0.999		0.999		0.999		0.981		0.981	
Mean	**0.751**		**0.307**		**0.231**		**0.279**		**0.851**		**0.783**	
Number of observations	104		104		104		112		112		112	

TE, AE and EE are technical efficiency, allocative efficiency and economic efficiency respectively

Determinants of production inefficiencies in cassava production by adopters of mobile-based ICTs

After measuring the level of TE, AE and EE, it was necessary to identify which demographic and socioeconomic factors influenced the level of TE, AE and EE in cassava production. The results are presented in Table 4. The negative sign of parameters means improving technical inefficiency, and vice versa.

The age of farmers was associated with decreases in TE and AE of the non-adopters; older farmers were technically and allocatively more inefficient than the younger ones. There was a positive and significant ($P \leq 0.05$) relationship between non-adopters' farming experience and TE; this implies that non-adopters of mobile-based ICTs with more farming experience were more technically inefficient. On the other hand, farming experience had a significant ($P \leq 0.1$) and negative effect on allocative inefficiency of adopters as well as economic inefficiency of both adopters ($P \leq 0.01$) and non-adopters ($P \leq 0.05$). This showed that farming experience of the farmers helps to improve the allocative efficiency of the adopters and the economic efficiency of both the adopters and non-adopters.

Farmers with more years of formal education had a negative coefficient and significant ($P \leq 0.05$) effect on technical inefficiency of the non-adopters and allocative inefficiency of both the adopters and non-adopters ($P \leq 0.01$), as well as economic inefficiency of the non-adopters. This indicates that farmers with more formal education were more efficient (technically, economically and allocatively) in cassava production than those with fewer years. Household size had a negative coefficient and significantly influenced technical ($P \leq 0.1$) and economic ($P \leq 0.05$) inefficiencies of adopters. This implied that the more people in the household, the more technical and economic efficient the adopters were.

Extension services offer guidance to the farmers related to the use of various resources such as fertiliser and provide consultancy services in managing their scarce resources more efficiently. Access to extension services had a negative coefficient and significant effect ($P \leq 0.01$) on the technical inefficiency of the non-adopters and allocative inefficiency of both adopters and non-adopters. That is, farmers who have access to extension services during the cropping period are more technically and allocative efficient than those who have no access to extension services during the cropping period.

The sex of cassava farmers was found to have a negative coefficient and significant ($P \leq 0.01$) effect on the level of economic inefficiency of both the adopters and non-adopters. Based on this, female adopters and non-adopters were more economically efficient than their male counterparts.

In line with our expectation, the number of mobile-based ICTs used by farmers has a negative coefficient and a significant ($P \leq 0.01$) effect on the level of technical, allocative and economic inefficiencies. This implies that, the more the use of these technologies, the more the farmers are technically, allocatively and economically efficient.

Access to credit allows farmers to enhance efficiency by removing money constraints which may affect their ability to apply inputs and implement farm management decisions on time. Access to credit had a positive coefficient and significant ($P \leq 0.01$) effect on technical and economic inefficiency of non-adopters and economic inefficiency of the adopters, but had a negative and significant ($P \leq 0.05$) effect on economic inefficiency of the non-adopters in cassava production. This showed that, while access to credit made the non-adopters more technically inefficient, it helps to improve their economic efficiency.

Table 4: Determinants of cassava production inefficiencies among adopters and non-adopters of mobile-based ICTs

Variables	TE				AE				EE			
	Adopters		Non-adopters		Adopters		Non-adopters		Adopters		Non-adopters	
	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P
Age	-5.319* (3.079)	0.084	-1.968** (0.905)	0.030	0.063 (0.150)	0.677	-0.131*** (0.049)	0.001	3.415 (2.892)	0.742	-1.480 (1.194)	0.936
Farming experience	0.064 (0.059)	0.287	0.032** (0.016)	0.046	-0.097* (0.051)	0.060	0.180 (0.224)	0.425	-0.148*** (0.065)	0.002	-0.167** (0.081)	0.045
Education	-0.495 (0.422)	0.242	-0.342** (0.158)	0.030	-0.055*** (0.021)	<.001	-0.143*** (0.011)	0.001	0.052 (0.110)	0.734	-0.052*** (0.016)	0.001
Household size	-2.277* (1.239)	0.066	1.339*** (0.364)	0.001	0.126 (0.083)	0.129	0.228 (0.259)	0.380	-3.465** (1.246)	0.012	1.011 (0.852)	0.498
Access to extension services	1.849 (1.956)	0.344	-2.927*** (0.565)	0.001	-0.295** (0.117)	0.014	-0.031*** (0.010)	0.001	1.893 (2.210)	0.700	-1.270 (2.168)	0.732
Sex	-1.2749 (0.914)	0.163	0.113 (0.288)	0.695	0.077 (0.070)	0.269	-0.013 (0.027)	0.324	-0.781*** (0.115)	0.001	-0.353*** (0.091)	0.001
Number of mobile-based ICTs used	-0.286** (0.114)	0.009	-	-	-0.103** (0.051)	0.012	-	-	-0.175** (0.083)	0.013	-	-
Access to credit	-1.396 (1.497)	0.351	2.181*** (0.667)	0.001	-0.103 (0.075	0.175	-0.431 (0.423)	0.310	1.423*** (1.185)	0.001	-1.652** (0.811)	0.048
Constant	43.126 (1135.407)	0.970	9.216*** (3.158)	0.004	0.337 (0.509)	0.510	0.979*** (0.002)	<.001	20.156*** (4.880)	0.001	-5.370*** (1.040)	0.001

TE, AE and EE are technical efficiency, allocative efficiency and economic efficiency respectively. Values in parenthesis are the standard errors. *, ** and *** significance at 10%, 5% and 1% respectively. A negative sign of an estimated parameter in the inefficiency model implies that the associated variable has a positive effect on efficiency but negative effect on inefficiency and vice versa

Discussion

Socioeconomic characteristics and determinants of production efficiencies of cassava farmers

The mean age of 48.3 years for adopters and 49.4 years for non-adopters is similar to the results obtained by Igbaifua (2018) in Guinea Savanah Zone of Nigeria, with a modal age group of 41-50 years and a mean age of 44 years. The size of the farm is a sign that both adopters and non-adopters operate on a small scale. The results of the impact of cost of farm land on AE imply that, if the cost of farm land is increased, the total cost of production of cassava by small scale farmers will increase.

The Stochastic Production Frontier function showed significant technical, allocative and economic inefficiencies in both adopters and non-adopters but with a higher level of inefficiencies among non-adopters than adopters. Farm size, labour, fertiliser and agrochemical use contributed significantly to the output of adopters, while agrochemical and cassava stem cuttings significantly affected non-adopters. These findings are consistent with existing studies on cassava production in Africa, which show that farm size, stem cuttings, and labour are important determinants of cassava output (Dogba et al. 2021; Missiame et al. 2021).

A positive coefficient of farm size and significant relationship between farm size and TE, and AE at 1% level of significance supports the notion that large land holding farmers are more likely to employ modern agricultural practices and hence, could be more efficient due to the advantage of the economic scale and scope associated with large farm size (Endrias et al. 2010). From the results in Table 2, an increase in farm size by 1ha would result in an increase in cassava output of adopters by 0.64 (64%) and non-adopters by 0.71 (71%), while an increase in farm size by 1ha would result in an increase in total production cost by 0.14 (14%) and 0.40 (40%) by adopters and non-adopters respectively. Similarly, an increase in the quantity of labour by 1 person/ha and fertiliser used by 1kg/ha would result in an increase in cassava output by 0.33 (33%) and 0.16 (16%) respectively, whereas, an increase in the volume of agrochemical by 1litre/ha by the adopters would increase the output of cassava by 0.21 (21%) by the adopters and decrease output by 0.31 (31%) by the non-adopters. This is expected as adopters may not have access to information via mobile-based ICTs on the correct usage of agrochemicals. In addition, the cost of cassava stem cuttings had a positive coefficient and significant effect on total cost of cassava production; a unit increase in cost of a bundle of cassava stem cutting per ha, will increase the total cost of adopters and non-adopters by 0.15 (15%) and 0.90 (90%) respectively. This was in line with Igbaifua et al. (2021), who found that cassava planting stem was a significant hindrance to cassava production in Oyo State, Nigeria.

From Table 3, the mean of TE of 75.1 of the adopters was similar to the efficiency level obtained in a previous study on cassava production in Nigeria, which stated that cassava farmers in Cross River State were 70% technically efficient (Nkang and Ele 2014). If cassava farmers, who adopted mobile-based ICTs, are going to achieve the TE level of their counterparts, they could increase output by about 25% (calculated as 1- (0.75/1.00) x100%), while the most inefficient farmers can increase output by about 98.3% (calculated as 1– (0.017/1.00) x100%) using the existing technology. Similarly, the non-adopters can increase output by 72.7% (calculated as 1– (0.28/0.99) x 100), while the most inefficient farmers under this category can increase their output by about 99.7% (calculated as 1– (0.0032)/0.99) x 100).

In Table 3, the maximum AE score of 0.999 by adopters show that the most efficient farmers operated almost on the frontier in the study area. From the results, the average cassava farmers who are adopters can save 68.7% (1 – (0.31/0.99) x 100) of their current cost of inputs if resources are efficiently utilised, while the non-adopters can only save 13.3% (1 – 0.85/0.98) x 100) of their current cost of inputs to be most allocative efficient. In addition, the result of EE indicates that if adopters were to reach the EE level of their most efficient counterpart, they can reduce their cassava production cost by 76.9%, (1– (0.23/0.99) x 100) with the existing technology, while the non-adopters can reduce their cassava production cost by only 20% (1– (0.78/0.98) x 100).

Discussion on determinants of production inefficiencies in cassava production by adopters of mobile-based ICTs

Younger farmers are probably not making the potential use of mobile-based ICTs to improve the TE and AE in cassava production in the study area. The higher allocative efficient of older farmers than younger farmers (Table 4) agrees with the study in Nigeria of Nwosu and Gbolagun (2021). Findings from this current study also shown that cassava farmers, with many years of production experience, have higher AE and EE than those with fewer years of farming experience. This result is consistent with a *priori* expectations and showed that farmers use their experience to utilise their scarce resources efficiently.

The finding that formal education of cassava farmers has a significant effect on production efficiencies of cassava farmers agrees with Mwebaze et al. (2022), who, showed that an increase in cassava farmers education, increased their production efficiency. Better educated farmers are expected, on their own, to understand agricultural instructions easily, have higher tendency to adopt mobile-based ICTs to improve production, have better access to information and are able to apply technical skills imparted to them, than uneducated ones. An increase in access to extension services, from the results of the study, shows that TE of non-adopters would increase by 2.9 (290%), AE of adopters by 0.30 (30%) and 0.03 (3%) by the non-adopters.

Results on the effect of access to credit on technical inefficiency implied that non-adopters, who had access to credit during the cropping period, were more technically inefficient than those who had no access, but economically efficient. Adopters with poor access to credit had lower levels of EE probably because of their inability to buy and make use of mobile-based ICTs. Use of mobile-based ICTs therefore is crucial to increase TE and EE of cassava production in the study area.

Results also showed that the more persons in the adopters' household, the more technically efficient the farmer was, while a large household size of a non-adopter made him technically inefficient. A possible reason for this result might be that a larger household size assists in the provision of family labour for farm operations to be accomplished in time by the adopters. This result agrees with the findings of Debebe et al. (2015), Wana and Sori (2018) and Tesema et al. (2019), who in their respective studies, found that households with large size are more efficient than farmers with smaller household size. The negative relationship with TE by the non-adopters agrees with Okello et al. (2019) and Wai and Hong (2020). This study in addition, found that female producers are more economically efficient than male counterparts. This finding agrees with Adetunji and Adeyemo (2012), and Awoyemi and Adeoti (2006), who also observed in their studies that female cassava producers are more efficient in resource use, than their male counterparts.

Cassava farmers in the study used mobile-based ICTs to ease communication thereby reducing traveling costs to agro-dealer stores for their farm inputs, for social interactions with other farmers, improvement in knowledge and skills (especially with the introduction of some specialised mobile-based applications like Akilimo, Cassava Seed Tracker, IITA herbicide calculator) in management practices to enhance their production efficiencies. The implications of the direct effect of the number of mobile-based ICTs with production efficiencies, is that, as cassava farmers increase the number of mobile-based ICTs, the more efficient they are. The finding agrees with Falola and Adewumi (2013), who found that using mobile telecommunications services has a positive and significant relationship to the TE of farmers.

Conclusion and recommendation

The study assessed the impact of mobile-based ICTs on production efficiency of the cassava producers in southwest Nigeria. The main conclusion is that cassava production efficiency is linked to use of mobile-based ICTs. Both adopters and non-adopters, in the study area, are not operating at full TE, AE and EE levels, suggesting room for increased output without increasing the level and costs of inputs. The main factors identified as contributing towards improving cassava farmers' production efficiencies include accessibility to credit, extension services, education and number of mobile-based ICTs used by farmers. The cost function analysis confirmed that farmland and cassava stem (cuttings) are major cost components of the cassava farmers for both adopters and non-adopters.

The positive and significant association of number of mobile-based ICTs used on TE, AE and EE, shows that improving the existing mobile-based ICTs and services should help to increase cassava farmers' production efficiency. Therefore, cassava farmers need to be sensitised by the extension agents, through jingles on social and print media on use of mobile-based ICTs in order to increase their production efficiencies.

Findings from this study contribute to studies on the relationship between farm size and efficiency. Farm size, which had a positive coefficient and significantly affected the TE and AE, provides an important lesson for other similar agro-ecology areas of small-size farm owners, that better efficiency in cassava production, with the use of mobile-based ICTs, could be obtained with an increase in their farm sizes.

The findings, which showed that female cassava producers are more economically efficient than male counterparts, implied that reducing gender efficiency gaps would require tackling gender gaps in accessing modern inputs, extension and financial services (credits in particular) if cassava efficiency is to be enhanced.

Education attainment level is an important factor in TE, AE and EE, the key policy implication is that appropriate policies should be designed to provide basic educational opportunities for farmers in the study area through training and capacity enhancement of the farmers and heads of farming units.

Based on the effect of access to extension service on TE, AE and EE, policies and strategies to strengthen the existing agricultural extension services through recruitment of more staff by government and private agencies at all levels, should be emphasised so the farmers can have access to their services in the study area.

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Author contributions

AEO prepared the draft manuscript and its revision; CAA and OFA contributed to the revision of this manuscript. FO and AMA conceived the idea of this concept. All the authors participated in the supervision of the data collection, methodology used and have read and agreed to the published version of the manuscript.

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