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INCENTIVIZING THE ADOPTION OF BIOFORTIFIED RICE FOR INCREASING FARMERS' PRODUCTIVITY AND INCOME DURING COVID19 ERA: EVIDENCE FROM SMALLHOLDER FARMERS IN NIGERIA

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Abstract

This research examined the challenges and factors affecting the behaviours of rice farmers towards adopting the bio-fortified rice technology in the Covid-19 pandemic era. The trust of the paper rests on despite the awareness and support to farmers to adopt the new bio-fortified rice technology and the importance of technology in farmers' welfare; the acceptance has been low and slow. More importantly, research in this area has neglected the factors influencing the adoption of biofortified rice and its impact on the production and income of the farmers in Nigeria during the pandemic era. This study used a multi-stage sampling procedure to select 540 (200 non-adopters and 340 adopters) rice, farmers. Data were collected using computer-assisted personal interviews (CAPI) and analyzed with descriptive and inferential statistics. The major result shows that the socioeconomic profiles of the adopters were better than the non-adopters. The decision by the farming households to adopt biofortified rice was significantly influenced by the household's income level, extension agent contact, credit, association with cooperatives and availability of information. In addition, adopting biofortified rice increased the adopters' income across all categories of inc12ome considered. The rice farmers faced general and specific Covid-19 challenges that constrained them from adopting the technology. It was recommended, among others, that emergency agencies whose duties are to mitigate the effects of a pandemic-related crisis should have offices in the rural areas to have close contact with the information needs of the rural farmers in times of emergency.

Key words: *bio-fortified rice, challenges, innovation, Covid-19, Nigeria*

INTRODUCTION

The world's second most popular cereal (after wheat) rice shapes the lives of millions of households worldwide. Rice accounts for about 80% of the world's food calorie requirements for more than half of the world's population [3, 13]. In Nigeria, it is a staple food that is consumed across all social divides, including poverty status, religion, tribe, and gender [18]. Growing population and income levels, in conjunction with the ease of preparing and storing it, could explain the rise in demand [3]. Rice production is characterized by peak seasonal labour demand and labour-intensive production, which made labour shortages a serious problem despite agricultural production being exempt from COVID-19 lockdown. The COVID-19 pandemic has brought a new risk to Nigeria's rice farmers, who are already facing the negative impact of climate change and greenhouse gas (GHGs) emissions [13, 17].

The Coronavirus (Covid-19) pandemic has created a landmark impact on food production since 2019, and virtually all aspects of the economy are expected to adjust to this effect, therefore demanding that more innovative innovations be adopted to cushion the challenges before us. At the beginning of the crisis, the food supply chains were constrained by domestic and international lockdowns, affecting the production and distribution of staple food like rice [11, 12]. Reduced rice production may have severe implications for staple food availability. The negative effect of the rice supply and demand chain by Covid-19means that farming household swill not be able to access a sufficient nutritious food supply thereby facing the worst food insecurity conditions [17]. Therefore, the pandemic has occasioned the need not just for increased rice production but, most importantly, the need for the intake of fortified gramineous plants at a reduced cost. Due to the rice endosperm is deficient in many nutrients, including vitamins, proteins, and micronutrients, fortification becomes important in fighting nutrient deficiencies through gramineous practices [45]. The Aleurone layer of the dehusked rice grain is a nutrient reach but is lost during milling and polishing. Therefore, this study investigates farmers' behaviour, productivity and challenges towards adopting this innovation in the Covid-19 pandemic era. Graminaceous plants, such as rice, have sophisticated mechanisms for acquiring micronutrients from soil and absorbing them from roots to grains by secreting small molecules called mugineic acids (MAs) such as *copper* (*Cu*), *manganese* (*Mn*), iron (*Fe*), and *zinc* (*Zn*)which are acceptable for use [45]. Sequel to this, the Nigerian government approved the adoption and expansion of bio-fortified rice targeted at improving its dietary intake and increasing local production [31]. However, this research is motivated by the fact that both field observations and literature suggest that the current Covid-19 pandemic has widened the gap between the demand and supply of locally produced nutrient-filled rice [4,5, 44]. Before the pandemic, the adoption of biofortified rice variety by the local farmers was still low and slow, which led to the production of staples with low micronutrients (vitamin *A*, iron and zinc) [45,27]. Consequently caused Nigeria to import rice (2,000,000MT in 2017, 1,900,000MT in 2018 and 1,800,000MT in 2019) despite all the measures taken by the government to increase local production [30]. [3] further noted that the most common micronutrient deficiencies found to be lacking in staples in Nigeria include vitamin *A*, iron, and zinc, with the prevalence rates of 29.5%, 26%, and 20%, respectively, in children less than five years. Also, micronutrient deficiencies such as lack of vitamin *A* have contributed significantly to estimated 600,000 child mortality worldwide, and lack of zinc contributes to about 400,000 deaths in children annually. In Nigeria alone, it has been statistically estimated that 25% of children under six years of age suffer from vitamin A *d*eficiency, which causes poor growth [2]. These problems could also lead to increased maternal and infant deaths. Studies have also shown that deficiency of vitamin *A* has caused 964,000 Disability Adjusted Life Years (DALYs) in Nigeria; this vitamin *A* dietary intake was inadequate in about 83% of preschool-aged Nigerian children [45, 2].

Closing these gaps (of poor yield and low micro-nutrient supply) as quickly as possible in this post-pandemic era depends mainly on farmer's acceptability of this innovation, increased consumer preference for the new product, access to farmers' credit, increased farmer education, and expanded extension services [27], as well as consistent and appropriate policies. Evidence of the poor, inconsistent, and inappropriate policies is clearly shown during the ban on rice importation. Nigeria was still importing thousands of tonnes of rice through many of her illegal trade routes. In the same line of thought, many research works have been done to investigate these rice production gaps without attempting to investigate the behaviour of farmers towards adopting this innovation and the major problems hindering its full adoption, especially in this pandemic crisis. Therefore, this present study aims to compare the socioeconomic attributes and input/income levels of adopters and non-adopters, determine the factors influencing farmers' behaviour towards bio-fortified rice production technology in the pandemic era, identify general constraints limiting the adoption of bio-fortified rice technology in Nigeria, and identify specific constraints associated with Covid-19.

MATERIALS AND METHODS

The study area is Nigeria, comprising northern and southern parts with distinctive rainfall patterns. Nigeria is located in West

Africa and lies in the northern latitudes between 4^0 and 14^0 and between 3^0 and 15^0 of the eastern longitude [19]. It has a 923,768 sq.km landmass and comprises 36 states and the Federal Capital Territory, 2 major regions (north and south), and six sub-regions in Figure 1 below. It is bordered to the north by the Republics of Niger and Chad. Nigeria's irrigated land is 9,570 km^2, while the arable land is about 35% of the total land area [3,2]. The major soil types in Nigeria have the potential for agriculture. Nigeria recorded 140,431,790 people in the 2006 national census but is estimated to have reached 200 million in 2019 [25]. Also, according to [26], Nigeria holds 182,000 cases and 2,520 deaths out of 178m cases and 3.86m deaths of the Coronavirus pandemic globally. Figure 1 shows the update of Covid-19 cases in Nigeria.

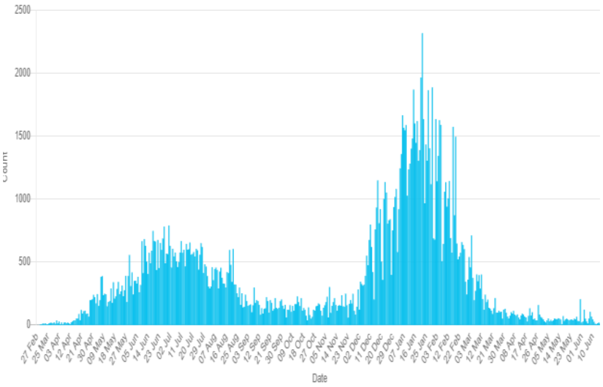

Fig. 1. Nigeria's update of Covid-19 cases till January 2021
Source: NCDC, 2021.

According to data from [25], food insecurity and unemployment are becoming more pronounced during this pandemic era, with the average poverty in Nigeria's headcount becoming the highest in Africa. According to [39], rice is the major staple produced in Nigeria, and as indicated in [16] it has served as an "object of food security". There are wide varieties of paddy rice grown in Nigeria. These varieties include FARO 14, 15, and 44, ITA 306 and 316, Mass 1 and 2, and NERICA, among others [3]. These are considered 'traditional' varieties because the farmers have been producing the varieties over the years. A newly introduced bio-fortified variety is also genetically improved with minerals and vitamins. In line with many efforts to reduce the menace of micronutrient deficiency, the Nigerian government, in collaboration with a broad spectrum of stakeholders, has been subsidizing the supply of bio-fortified rice seeds. This intervention is expected to increase productivity and reduce nutrient deficiency among women and children. According to [10], Nigeria has seen remarkable progress in rice production in the past ten years, with growth rates of 1.3% and 2.3% for 2018 and 2019, respectively.

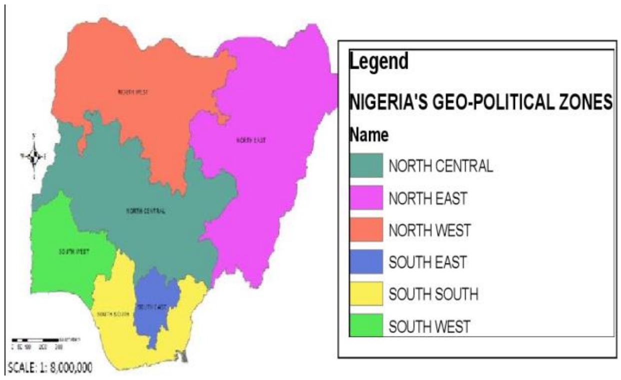

Fig. 2. Map of Nigeria showing north (northwest, northeast, and north-central) and south (east, southwest, and south-south).
Source: Google Maps.

There are many varieties of paddy rice grown in Nigeria. These varieties include FARO 14, 15, and 44, ITA 306 and 316, Mass 1 and 2, and NERICA, among others [20,38]. These are considered 'traditional' varieties because the farmers have been producing the varieties over the years. A newly introduced bio-fortified variety is also genetically improved with minerals and vitamins. In line with many efforts to reduce the menace of micronutrient deficiency, the Nigerian government, in collaboration with a broad spectrum of stakeholders, has been subsidizing the supply of bio-fortified rice seeds. This intervention is expected to increase productivity and reduce nutrient deficiency among women and children. According to the [37,45], Nigeria has seen remarkable progress in rice production in the past ten years, with growth rates of 1.3% and 2.3% for 2018 and 2019, respectively.

Sampling

Multi-stage sampling procedures involving purposive and random sampling techniques were used to select respondents for this study Figure 2).

Nigeria was delineated into northern and southern regions in the first stage for administrative convenience. Three states were purposively selected from each region based on their relative dominance in rice production. Ebonyi, Anambra, and the Enugu States were selected in the southern part, while Adamawa, Gombe, and the Taraba States were selected from the northern part. The second stage involved selecting two Local Government Areas (LGAs) that are dominantly involved in rice production from each of the six states, totalling 12 LGAs. In the third stage, communities were selected in proportion to the number of rice farming villages in the LGAs.

The proportionality factor adopted for the study is shown thus:

$$\mathrm{Xi} = \frac{\mathrm{n}}{\mathrm{N}} * 100 \qquad (1)$$

where:

Xi= number of rice farming communities sampled in each LGA

n=number of farming communities in a particular LGA

N= Total number of farming communities in all the selected LGA.

From a list of biofortified rice farmers, 20 rice-producing communities were randomly selected. From the list, 15 households that have access to biofortified rice and use it were selected at random, and 5 households that have access to biofortified rice and did not use it were randomly chosen, making a total of 620.

However, only 540 instruments (340 adopters and 200 non-adopter) were completed, retrieved, and collated using computer-assisted personal interviews (CAPI).

Binary Logit Model

The Logit model was used to achieve objective two of this study. The empirical model is specified thus:

$$\mathrm{Y}_i = \frac{1}{X_{ij}} = (\mathrm{F}\,(Z_i)) = (1/1 + \mathrm{e}^{-\mathrm{zi}} = \mathrm{e}^{\mathrm{z}}/\mathrm{e}^{\mathrm{z}} + 1) \qquad (2)$$

where:

$$\mathrm{Y}_i = \mathrm{Z}_i = (\alpha, \beta_1 X_{1j}, \beta_2 X_{2j}, \ldots \beta_8 X_{8j}), \varepsilon$$

Z_i is the theoretical likelihood of the sample formed by introducing a dichotomous response variable Y_i such that Y_i is either 0 or 1.

Y_i= 1 if the i^{th} farmer is an adopter of bio-fortified rice farming innovation

Y_i = 0 if the i^{th} farmer is a non-adopter of bio-fortified rice farming innovation

j = 1- 8 variables in Table 1

i = 1 to 540 (total number of respondents)

X_{ij}= socioeconomic and institutional profiles of the i^{th} farmers as in Table 1.

$\beta_1$to $\beta_8$are parameters of estimates from the variables under study

α = constant term

ε = disturbance term.

Variable specifications in the model

The measure of innovativeness developed for this study was based on the number of farmers who had adopted the fortified rice innovation. Given that nearly all the farmers had adopted at least one innovative technology, such as improved seed varieties, fertilizer, herbicide, and/or insecticide, the respondents were classified into two categories of innovativeness: non-adopters and adopters.

Table 1. List of variables used in the study

SN	Variable	Variable code	Description and unit	*A priori*
1	Households' farm income	Income (X_1)	Revenue from farming (Naira)	+
2	Access to information	Info (X_2)	Number of extension visits (number of visit)	+
3	Access to credit facilities	Credit (X_3)	Reasonable loan Obtained to finance farming operation (Yes, 1; No, 0)	+/-
4	Educational status	Literacy (X_4)	Years of formal education attained (years)	+
5	Farming experience	Exp (X_5)	Period of years engaged in rice farming (years)	+/-
6	Total farm size	Size (X_6)	The a priori expectations for the variables (hectares)	+
7	Household size	People (X_7)	Individuals in a household (number)	+/-
8	Membership of cooperative group	Club (X_8)	Membership of cooperative groups (If affiliated = 1, 0 otherwise,	+

Source: Authors' conception.

A farmer is said to be an adopter if the farmer fully adopts the bio-fortified rice innovation.

Based on the previous, 200 farmers were identified/ classified as adopters, and 340 were identified/classified as non-adopters. This provides a valuable basis for empirical analysis of the underlying factors contributing to a farmer's decision to adopt the new farming techniques. The *apriori* expectations for the variables, codes and units as used in this study are described in Table 1.

Pre-estimation tests

Before using the logit model, multi-collinearity was checked to exclude any highly correlated explanatory variables. The results indicated low and tolerable levels of multi-collinearity in the data using Variance Inflation Factor (VIF), and condition index (CI). Multi-collinearity is more troublesome if there is a larger value of VIF. As a rule of thumb, if the VIF of a variable exceeds 10, the variable is said to be highly collinear [43].

Following [43], the VIF_j is given as:

$$VIF(X_j) = 1/1 - R^2 j \quad ………….............(3)$$

where:

$R^2{}_j$ is the coefficient of multiple determinations when the variable X_j is regressed on the other explanatory variables. There may also be interaction between categorical (dummy) variables, which can lead to the problem of multi-collinearity. To detect this problem, Phi (φ) coefficients were computed.

The Phi (φ) coefficient was compounded as follows:

$$\varphi = \sqrt{\chi 2} / n \quad ……………......................... (4)$$

where:

φ is the phi coefficient; χ2 is chi-square test and n = total sample size.

If the value of the Phi coefficient is greater than 0.5, the variable is said to be collinear [43].

Computing household income

In this study, the biofortification program's adoption was determined by its adopters' income gains. Some studies have found that directly measuring income is laborious [43]. Expenditures have been used as a proxy instead of household income. Despite these arguments, the study used three monetary measures: household income, total income, agricultural income, and per capita income. By asking the sampled households to disclose their monthly monetary income by source, we could estimate the income of the households in the sample. In this way, income data could be improved. In order to calculate each income source's contribution to the cash, we use the following equations:

$$Y_i = \sum y_{i,k}$$
$$y^*_{i,k} = \frac{y_{i,k}}{Y_i} \quad ……………................. (5)$$

The following formula was used to calculate household daily per capita income.

$$PCI_i = \left(\frac{Y_i/365}{Hs_i}\right) .... (6)$$

For the first step, the household total income was divided by 365 in order to calculate the household daily income. Using this income, we can determine the household daily per capita income by dividing it by the household size, Hs. Rice-producing households were compared based on their household daily per capita incomes. Additionally, it provided an indication of the poverty status of the households. We estimated household income following the adoption of biofortified rice using the treatment effect estimation approach. In addition to being counterfactual-based, this method of estimating impacted outcomes also produced consistent estimates [43].

Farmers' adoption status is reflected by Y, while outcomes are reflected by T. Using the counterfactual framework, adopting a biofortified rice variety can result in two potential outcomes (i.e. Y = Y1 if T = 1 and Y = Y0 if T = 0). The average effect of adoption, also referred to as the average treatment effect, ATE, is generally calculated as follows:

$$ATE = E(Y_1 - Y_0) \quad ……….......................... (7)$$

As a result of differences in knowledge, access to information, and physical accessibility, [7] anticipated unequal adoption opportunities. As a result of adoption status, the average treatment effect on the treated ATT can be expressed as follows:

$$\text{ATT} = \text{E}\big((\text{Y}_1 - \text{Y}_0) \mid \text{T} = 1\big) \quad \ldots\ldots\ldots\ldots(8)$$

To adopt biofortified rice, access to the product was the most important factor. However, despite having access to seeds, some farmers may not have planted them.

This implies that some farmers complied while others did not. In this case, the local average treatment effect (LATE) measures the impact on the farmers who received seeds and planted them. According to LATE, the following parameters were used:

$$\text{LATE} = \text{E}\big((\text{Y}_1 - \text{Y}_0) \mid \text{P} = 1, \text{T} = 1\big)\ldots.(9)$$

The Econometric Procedures

The study assumed that some exogenous factors also influenced the adoption of biofortified rice, X, such that the following formulas could calculate potential adoption outcomes; in terms of X and the unaccounted factor, μ, was given by:

Some exogenous factors may influence the adoption of biofortified rice, X , so the following formulas calculated potential adoption outcomes; in terms of and the unaccounted factor, μ, was given by:

$$\text{Y} = \text{Y}_1 = \text{X}\beta_1 + \mu_1 \text{ if T} = 1$$

and

$$\text{Y} = \text{Y}_0 = \text{X}\beta_0 + \mu_0 \text{ if T} = 0$$

With these, the LATE was re-expressed as:

$$\text{LATE} = \text{X}\beta_1 - \text{X}\beta_0 + \text{E}(\mu_1 - \mu_0 \mid \text{X}, \text{T} = 1, \text{P} = 1)\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Subsequently, the observed income, $Y = Y_1 + Y_0$, was expressed in terms of the LATE as:

$$\text{Y} = \text{X}\beta_0 + \text{T} * \text{LATE} + \varepsilon_{\text{LATE}} \ldots\ldots\ldots (11)$$

A two-stage instrumental variable regression procedure was used to estimate the LATE parameter. An adoption model was estimated with access to seeds of biofortified rice, P, as an instrument, W, as additional explanatory variables, and γ as coefficient estimates in the first stage. The model is specified as follows:

$$\text{Prob}(\text{T} = 1) = \Phi(\text{PW}\gamma) \ldots\ldots\ldots\ldots\ldots (12)$$

The estimation of the LATE model with the predicted probability of adoption is the second stage in the analysis process. The model was also specified as:

$$\text{Y} = \text{X}\beta_0 + \widehat{\text{T}} * \text{LATE(X)} + \varepsilon_{\text{LATE}}\ldots\ldots\ldots (13)$$

RESULTS AND DISCUSSIONS

The result of this research is presented below in line with the study objectives.

Rice production factors and socioeconomic characteristics of rice farmers in Nigeria

The respondents (rice farming households) were categorized into two groups – adopters and non-adopters of bio-fortified rice technology. A comparative summary of their resource inputs and major socioeconomic characteristics showed that the population of adopters was 37%, while non-adopters stood at 63% (Table 2). This suggests that the level of adoption among rice farmers in Nigeria is still relatively low, despite all the efforts by the government and other stakeholders. This is in line with other studies Such as [36, 14], which further opined that farmers could be critical in accepting new varieties to preserve the cherished indigenous or traditional rice varieties. The findings also showed adopters had better socioeconomic attributes such as higher rice output, less dependence on family labour, higher income, use of more paid labour, use of more fertilizer and herbicide, higher educational attainment and more number of extension visits [1]. All these may have contributed to their positive behaviour towards adopting the new technology more than their counterparts.

Though the research expectation was that more farming households would have adopted the technology, there is a general belief that any technology introduced and supported by the government is for their good. Also, the *apriori* expectation of this study was based on the research by [4], that judicious use of technologies improves efficiency. However, maybe because improved technology is expected to come with costs, risks and uncertainty, only farming households with better supporting attributes ventured into adopting bio-fortified rice technology. In line with this finding, [16] also noted that farmers who adopt better technologies had better chances of selling at a better price, thus, having a better socioeconomic outlook. Also, many other researchers believe that technology influences farmers' participation behaviour [14].

This study also showed that adopters were more economical with the bio-fortified rice seedlings than the non-adopters using the traditional seedlings in terms of planting and spacing. The seed rate of 60kg/ha on average was used by adopters, which is closer but slightly below the FAO-recommended 80kg/ha. In comparison, the non-adopters with an average seed rate of 102kg/ha planted even more than the recommended rate. This difference could be attributed to the adoption or use of the new seed is costlier than the existing species, and the non-adopters planted the traditional varieties obtained or sourced from the previous year's harvest. This is also supported by [15], who noted that the quantity and quality of rice seed planted by farmers depend on the price per kg, seed varieties, and technology access, among others. However, the recommended quantity of seed per hectare of upland and lowland rice production system was put at 100kg/ha [37]

Lastly, on the socioeconomic characteristics of the adopters and non-adopters, there were significant differences in farm income, education and extension visits at 1% level. However, their age, household size and farming experience were closely the same. This suggests that a number of extension visits/training, income and education levels were some of the major issues affecting their decision to adopt or not.

Table 2. Summary statistics of Rice Production Inputs and Socioeconomic Characteristics of the Paddy Rice Farmers

Variables	Adopters		Non-adopters		P > T
	Mean	St.Dev.	Mean	St.Dev.	
Paddy rice output (kg)	2633.5	1537.2	1593.9	837.6	0.00***
Farm size (Ha)	1.2	0.6	0.9	0.5	0.00***
Rice Seed (kg)	59.6	35.6	102.2	42.2	-0.65
Household’s labour (man-days)	46.0	63.5	65.5	65.3	-0.43
Paid labour (man-days)	60.0	64.7	25.2	55.8	0.05**
Fertilizer (kg)	149.4	96.7	83.9	47.8	0.01***
Herbicide (liters)	3.0	1.7	1.1	0.9	0.00***
Monthly Income (N)	29,291.61 ($68.12)	10451.6	15,148.91 ($35.23)	5899.8	0.00***
Age (years)	34.6	6.6	51.6	11.7	-0.21
Household size (number)	7.7	6.2	14.4	8.4	-0.32
Educational level (years)	7.5	5.6	3.8	4.9	0.00***
Extension contact (number)	7.6	2.5	2.4	2.3	0.00***
Farming experience (years)	12.6	6.31	12.0	5.9	0.65
number of observation	200	340	-		

*** Significant at 1% ** Significant at 5%, SD = Standard Deviation.
Source: Field survey, 2021.

This is also related to the study of [19, 21], which emphasized that education, extension contact, age and family size are some of the main determinants of technical efficiency among rice farmers in Nigeria and Ghana, respectively. Also, [20] stated that the same socioeconomic characteristics contribute 38% of the variation in rice output.

Income of adopters and non-adopters of biofortified rice in Nigeria

Using descriptive statistics shows that there is a significant difference between the adopters and non-adopters of biofortified rice across all the income categories (Table 3). For instance, the total monthly income of adopters and non-adopters of biofortified rice farmers were N15,148.91($35.23) and N29,291.61($68.12), respectively. In addition, the average percentage change for adopting biofortified rice was 88% for all income categories, suggesting a significant improvement in adopters' income. However, rice farmers' monthly average per capita and average monthly income increased by 47% and 74% for adopting and not adopting biofortified rice, respectively. It is also important to note that daily per capita income for adopters and non-adopters were N2175.80 ($5.06) and N3,198.43 ($7.49), respectively. This result suggests a wide variation in the income distribution of households as a result of the adoption of biofortified rice. Similar result was reported by [7, 24]. Who reported a significant increase in income of rice adopters in Ghana [14, 8]. However, this result will be tested with instrumental variable analysis to identify the Local Treatment Effects (LATE) to approve or reject the effect of adoption on farmers' income.

Table 3. Incomes of sampled adopters and non-adopters of biofortified rice

Activities	Non-adopters	Adopters	% Change	t-cal> |t|
Daily per capita income	N2175.80 ($5.06)	N3,198.43 ($7.49)	47%	0.00
Total income (Monthly)	N15,148.91 ($35.23)	N29,291.61 ($68.12)	93%	0.00
Rice Income (Monthly)	N8,432.30 ($19.61)	N14,645.80 ($34.06)	74%	0.00
Total agricultural Income (Monthly)	N11,360.66 ($26.42)	N21,973 ($51.10)	93%	0.01

Source: Computed from field data.

Determinants of the adoption of bio-fortified rice among the farmers in Nigeria

The result only reported the LATE values. This is because the OLS estimation of the impact parameters had no significant results, and there was a positive selection bias. Other treatment effect estimators improved results. OLS models with an interaction between adoption status and other covariates in the model solved the problem of selection bias. Except for rice income, where adoption had a significant positive impact on adopters, there was no significance in all other income categories. In addition, PSM eliminated selection bias in outcomes associated with positive adoption status. There was no statistical significance among any of the estimated impact outcomes. The study then applied access to biofortified rice as an instrument to correct for endogeneity in adoption; the estimated LATE parameters were significant for all the income categories and were discussed.

A binary logistic regression model was used to examine the factors influencing the adoption of the new rice production technology. The farmers were classified into adopters and non-adopters of new rice production technology. Eight possible determinants of rice production technology were used as the exogenous variables. The result of the likelihood ratio estimated indicated that all the Chi-square statistic was significant ($p < 0.001$), which suggests that the models were adequate for explaining the determinants of improved technology in rice production. This also shows that the model fits the data.The overall test shows that socioeconoimc characterisitics significantly affected the farmers' decision to adopt the rice production technology. In addition, about 55% of the total variation for adopting bio-fortified rice farming innovation were explained by independent variables. The marginal effects of the logit regression are presented in Table 4.

From the result, the decision by the farming households to adopt the bio-fortified rice farming innovation was significantly influenced by the household's level of income ($p<0.001$); this indicates that a unit increase in the households' income increased the likelihood of the farmers' innovativeness towards adopting the technology. It was expected that as farmers' income rises, the respondents would have more capital to invest, thereby having more capacity to take risks associated with adopting new technology. This is in consonant with findings of [26]. However, [29] reported that income alone does not guarantee adoption of biofortified rice farming, according to the author, it is only when the superior intention of the farmers to adopt based on income supersedes social benefit that makes income has significant influence. The coefficient of access to credit facilities was also positive and significant (P<0.001). The significance of the variable stemmed from the fact that access to agricultural credit is an important factor in making decisions about innovation adoption. Some studies support this finding [16, 22, 41]. These researchers argued that the fungibility of funds could deter its importance in adopting new technology.

Furthermore, access to extension officers (the number of visits by the extension agents to farmers) was positively significant (P<0.005). This means that skills and knowledge gained from the extension officers can influence Farmers' decisions to adopt new technologies [20, 1]. Membership of farm clubs or organizations such as cooperative societies had a positive and significant (p<0.01) influence on the adoption behaviour of rice farmers.

This agrees with [19, 26], who opined that membership in farm groups should be an added advantage in gaining access to information, credit, and skills.

Table 4. Parameter estimates of the Binary Logit regression of major factors influencing the adoption of bio-fortified rice innovation

Variables	Coeff.	Standard error	Wald	Significance	Exp (B)
Constant	-3.71	1.90	4.9	0.00***	0.0
Income	0.11	0.02	20.3	0.00***	2.5
info	0.82	0.21	22.8	0.00***	2.3
credit	3.90	0.90	19.6	0.00***	0.0
Edu	0.21	0.19	5.2	0.07	1.2
exp	-0.00	0.11	0.0	0.28	1.1
h-size	0.10	0.72	0.0	0.14	1.2
Extension	-0.30	0.21	5.1	0.00**	0.8
farm clubs	2.21	0.82	6.7	0.00***	1.1
number of observations			540		

*** Significant at 1%; ** Significant at 5%;-2 log-likelihood 61.548
Chi-square ($\chi 2$) 294.359***; Predicted Adopter 54%; Non-adopter 56.5%; Overall 55.3%.
Source: Field survey, 2020/21.

Constraints limiting the adoption of bio-fortified rice technology in Nigeria

The multiple responses from the farmers are presented in Table 5, and it shows the ranking order of the major constraints limiting the adoption of bio-rice technology in Nigeria. The result indicates that the most critical constraints faced by the farmers in order of seriousness were poor access to affordable and reliable farm inputs, inadequate credit facilities, conflicts with Cattle grazing nomads, and activities of middlemen. A similar result has been found elsewhere [21]. In addition, a study by [34] indicated that though access to input could be a critical factor in adoption, farmers are often discouraged from adopting when adulteration of the same input fills the market. The paper advocates the direct provision of new seed technology to farmers without passing it through middlemen. In addition, herders have remained the major concern of crop farmers in North Central and Southern Nigeria [2]. Other constraints were inadequate extension support, rainfall, and unfavourable land tenure systems. The result shows that some challenges were critical (above 50%). For instance, the majority of rice farmers (96.3%) were faced with poor access to affordable farm inputs (ranked first most critical challenge), while 90.8% were constrained by inadequate credit facilities (second most critical challenge). Also, the consistent conflicts between crop farmers and herders (89%) ranked third most critical factor. This was followed by economic activities of the middlemen (82%), attacks by birds (77%) and inadequate extension services (74%).

Table 5. Critical constraints limiting the adoption of bio-fortified rice technology in Nigeria

Constraints	Number of farmers	%	Rankings
Poor access to affordable farm inputs	260	96.31	1
Inadequate credit facilities	245	90.75	2
Conflict with grazing nomads/herdsmen	240	89.00	3
Activities of middle-men	220	82.45	4
Covid-19 pandemic	210	77.75	5
Inadequate extension support	200	74.08	6
Inadequate rainfall	102	37.78	7
Land tenure problems	80	29.63	8

Source: Field survey (2021).

These findings are in line with [41, 42], which identified inadequate credit, inaccessible roads, inadequate extension support, inaccessibility to cheap farm inputs, high cost of transportation and birds' invasion as significant constraints faced by rice farmers.

Impact of the adoption of biofortified rice on household income

The result only reported the LATE values. This is because the OLS estimation of the impact parameters had no significant results, and there was a positive selection bias. Other treatment effect estimators improved results. OLS models with an interaction between adoption status and other covariates in the model solved the problem of selection bias. Except for rice income, where adoption had a significant positive impact on adopters, there was no significance in all other income categories. In addition, PSM eliminated selection bias in outcomes associated with positive adoption status. There was no statistical significance among any of the estimated impact outcomes. The study then applied access to biofortified rice as an instrument to correct for endogeneity in adoption; the estimated LATE parameters were significant for all the income categories and were discussed.

The result shows that across all income categories, the estimated LATE parameters were significant when using access to biofortified rice seeds as an instrument to correct endogeneity problems (Table 6). Rice income increased by USD 0.24 for farmers with access to and planted biofortified rice seeds. In addition, their agricultural income rose by USD 0.30 while their total agricultural income improved by USD 0.73. The per capita income rose by 0.001 as a result of the adoption.

Table 6. Impact of biofortified rice seeds on across farmers' income categories

Parameters	Rice Income		Agricultural income		Per capita income		Total Income	
	Coeff	P>|t|	Coeff	P>|t|	Coeff	P>|t|	Coeff	P>|t|
ATT	31.67	0.42	102.00	0.27	0.24	0.30	178.08	0.29
ATE	22.30	0.66	131.01	0.37	0.09	0.27	120.08	0.34
ATU	2.87	0.83	93.00	0.51	0.06	0.43	107.27	0.59
Selection Bias	21.53	0.65	11.73	0.81	0.13	0.33	32.13	0.75
LATE	103.65	0.00	313.04	0.00	0.31	0.00	329.00	0.00

Source: Computed from field survey (2021).

This result is supported by [23, 8], who report that adoption has a significant increase in the income of the farmers.

COVID 19-related constraints to adoption of bio-fortified rice technology

Weighted mean, standard deviation and rankings were used to examine the decision on the level of agreement by the respondents on each element of the COVID-19 pandemic constraints. [40] used a similar methodology because of the unavailability of empirical data. The element with the highest weighted mean ranked first and was considered the element with the highest agreement (influence) by the respondents as the most challenging to adopt bio-fortified rice technology. Any element with a standard deviation below 1.96 indicates that the respondents were not far from the mean and the opinion of one another, while elements with a standard deviation above 1.96 indicate that the respondents were far from the mean and the opinion of one another. Table 7, shows that the inability of the farmers to access inputs (fertilizer, chemicals, and labour) due to the covid-19 lockdown was the highest-ranking element (with a mean of 4.0) that prevented the farmers from using the new technology. The result is supported by [41, 6]. The second highest element (with a mean of 3.86) associated with the COVID-19 pandemic was the farmers' inability to access markets to sell off harvested paddy rice due to the lockdown. Though the result is supported by [32,9], other studies suggested different results where access to the market is not a major obstacle to selling their products during a pandemic [23, 35]. The fact that although during the lockdown, agricultural input was given the concession to move from one location to another, their movement was limited because some places that were observing strict COVID_19 protocols [33, 10].

As expected, the third most influential elements of the Covid-19 constraints were risks and uncertainties associated with the pandemic (3.85), followed by price/market instability (3.84). Fear of contracting the covid-19 disease from other people (3.47) ranked 5th. The low access to finance and stiffer measures to loan applications during the pandemic (3.30), the perishable nature of paddy rice (2.7), no access to extension officers due to lockdown orders (2.60), and the exploitative activities of the middlemen during the pandemic (2.59) ranked 6th, 7th, 8th, and 9th respectively.

Table 7. Elements of the Covid-19 pandemic constraints

S/N	Covid-19 Pandemic constraints	Mean	SD	Rank
1	Inability of the farmers to access inputs (fertilizer, chemical, labour) due to covid-19 lockdown	4.0	0.00	1st
2	Inability of the farmers to have access to markets to sell off harvested paddy due to lockdown	3.86	0.46	2nd
3	Fear of contracting the covid-19 disease from other people	3.47	0.75	5th
4	No access to extension officers due to lockdown orders	2.60	0.81	8th
5	Low access to finance stiffer measures to loan application due to the pandemic	3.30	0.52	6th
6	Price/market instability	3.84	0.36	4th
7.	Perishability nature of paddy rice	2.74	0.94	7th
8	Exploitative activities of the middlemen during the pandemic	2.59	0.24	9th
9	Absence of incentives/palliatives to cushion the effects of the lockdown	2.30	0.22	10th
10	Risks and uncertainties associated with the pandemic	3.85	0.34	3rd

*SD – standard deviation
Source: Own results.

The least influential element associated with the pandemic was the absence of incentives/palliatives to cushion the effects of the lockdown (with a mean of 2.30). Although other studies supported this result [28, 15], the ranking was different in some other studies [22, 42].

The COVID-19 protocols for average rural farmers that were not educated increased the inability to access or observe pandemic protocols in the banking hall. This is enough limitation, as reported by [12].

CONCLUSIONS

The outbreak of the Covid-19 pandemic in December 2020 brought an abrupt halt to most economic activities, including farming. The pandemic also highlighted the need for the consumption of sufficient macronutrients, especially in staple foods like rice. However, despite the government's awareness and support, as well as the immediate need for an increase in bio-fortified rice intake, the adoption is still low, and farmers are still risk averse to adopting this new technology even when they have access. This results in financial instability and a general lowered standard of living occasioned by the pandemic. The study identified some socioeconomic and institutional factors affecting the adoption of biofortified rice. Adopting biofortified rice could be a better strategy to increase farmers' income and productivity, as revealed by its significance across all income categories. The study, therefore, suggests that policy efforts should be geared towards improving the general living standards of the farmers so that they can afford the risks of trying out emerging technologies. One way this can be done is to enable financial institutions to create rural/farmer credit, and educational programmes for rice farmers since access to credit and information are positively associated with adopting the new technology. Alternatively, Farmers can be encouraged to form cooperatives and other farm organizations to enable them to solve some of their productivity issues using group dynamics and to share resources, skills, and experiences.

Furthermore, investigation suggests that the government is making substantial efforts to provide palliative measures for the farmers. However, the government's efforts barely reach the farmers due to the challenge of farmer herder conflicts and lack of access on the farmers' side. Government policies should be prioritized towards finding a lasting solution to the crop farmers-herders crisis by compelling the herders to embrace modern ranching techniques. Also, emergency agencies whose duties are to mitigate the effects of pandemic-related crises should have offices in the rural areas to enable them to have close contact with the rural farmers in times of emergency and information asymmetric.

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