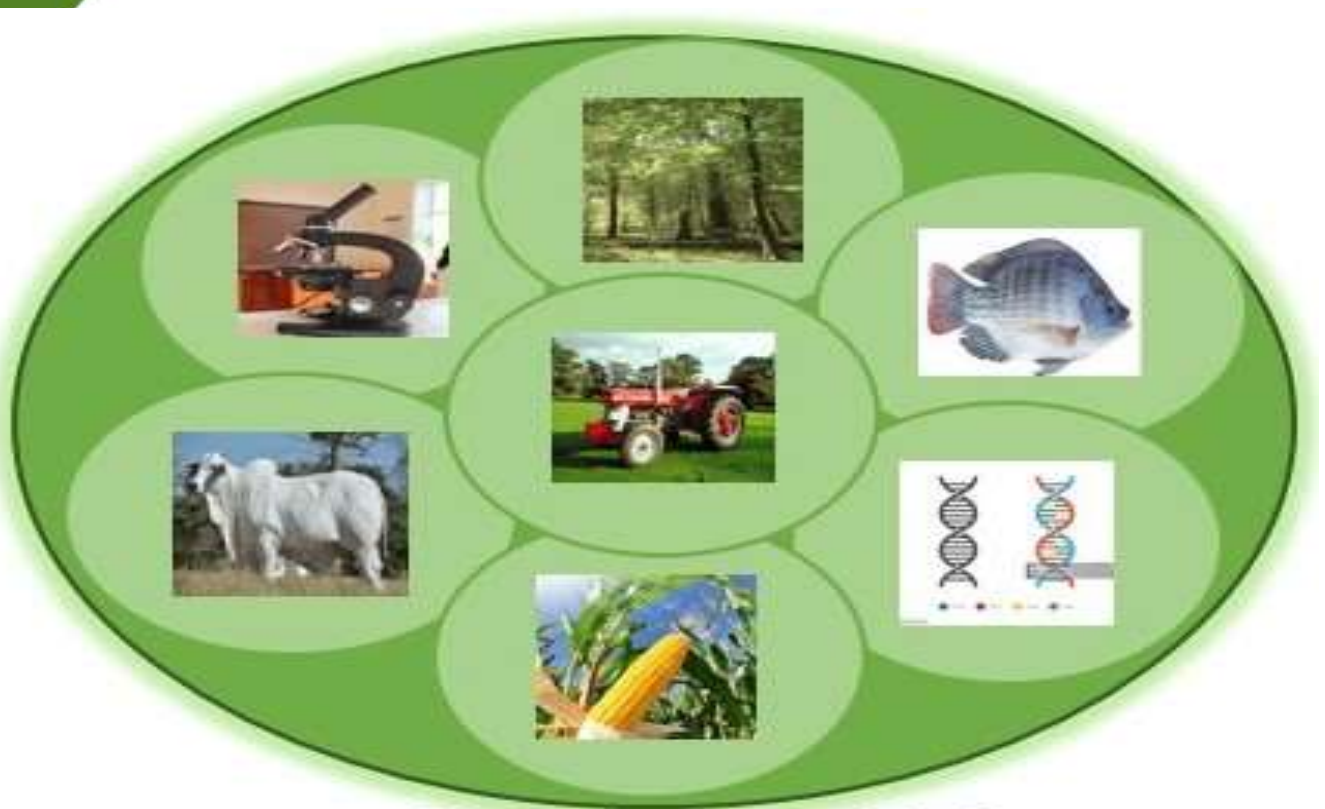




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CONTACT:

The Editor-in-Chief,
Kebbi Journal of Agriculture and Natural Sciences,
Faculty of Agriculture,
Abdullahi Fodio University of Science and Technology
Aliero,
PMB 1144, Birnin kebbi, Nigeria.
Email: kejaanseditor@ksusta.edu.ng,

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IMPACT OF WAVE-CDMTS ADOPTION ON FOOD SECURITY: EVIDENCE FROM NORTH WEST AND NORTH EAST NIGERIA

Abdussalam Adamu Jega^{1*}, Halima Muhammad Kure¹, Yahaya Kaka¹, Ibrahim Umar Mohammed¹, and Justin Simon Pita²

¹ Kebbi State University of Science and Technology Aliero, Kebbi State, P.O.Box 1144, Nigeria;
kebbistateuni.alihero@yahoo.com

² Central and West African Virus Epidemiology (WAVE), Scientific and Innovation Hub of Bingerville, Félix Houphouët-Boigny University (UFHB), Abidjan 22 BP 582, Côte d'Ivoire;
justin.pita@wave-center.org

* Correspondence: aajega29@gmail.com

ABSTRACT

Agriculture plays an important role to the economy of Nigeria, however, with high risks of natural factors like climate change, pests and diseases among others, pose significant threats to agricultural production, food security and livelihoods in Northern Nigeria resulting to low yields. Therefore, the need for farmers to insure their farms against crop loss is crucial. This study, evaluates the impact of WAVE-CDMTs adoption on food security of smallholder farmers in Northern Nigeria. The study utilizes cross-sectional data which was collected in 2023 from a randomly selected sample of 536 households (254 in North West and 282 in North East) using structured questionnaire (kobo collect). The data collected from the sample households were analyzed using endogenous switching regression model which account for both selection and endogeneity bias. The result of the analysis revealed that adopting Cassava Disease Management Technologies significantly increase food security through increased dietary diversity. Moreover, the difference in household dietary diversity between the actual and counterfactual scenarios is very high. The findings of the study reveal that broader investment in WAVE-CDMTs and increased access and adoption of agricultural technologies significantly improve the livelihood of farm households. This could be achieved by empowering households through adequate training and education on WAVE-CDMTs

Keywords: food security, technology adoption, Cassava, endogenous switching regression, Nigeria.

Introduction

Cassava, also known as *Manihot esculenta*, is a tuber crop that is being used as one of the basic and mainly consumed food in different countries (Fathima *et al.*, 2023). Cassava is an important food security crop in many African farming systems and provides more than half of the dietary calories to over 700 million people in Africa (Szyniszewska, 2020;

Amelework *et al.*, 2021). Cassava is produced mainly by smallholder farmers whose average cultivated area is less than one hectare (ha) (Mujuru and Obi, 2020; Dzanku *et al.*, 2021). Most of their production is for household consumption or sold as a food crop to domestic markets (Scott, 2021). It is mainly grown under intercropping systems with other crops such as

maize, legumes, and bananas (Monteiro *et al.*, 2020; Ravi *et al.*, 2021).

Cassava is a crop with enormous potentials. It provides a stable food base for the food need of the populace, components in livestock feeds and raw materials for industries (Amelework, 2021). Cassava also seems to be recording resounding success in sub-Saharan Africa out of the numerous stories of crop intervention failures in the region. As a result of this, many African countries have embraced its cultivation with renewed vigor (Sanusi *et al.*, 2021). Nigeria is one of such African countries. Almost every household in rural Nigeria grows cassava on small farms as one of the staple food crops to feed families and supply the local markets (Nanbol and Namo, 2019; Ndjouenkeu *et al.*, 2021). Cassava has high tendency to serve as a relief crop to food insecurity because of its copious consumption in various forms by people and its ability to subsist and give appreciable yields on soils where many other crops fail to perform, has endeared its cultivation by many smallholder farmers (Anaglo *et al.*, 2020). This was further supported by the assertion of Anyeagbunam, *et al.*, (2015), that cassava has become a very popular crop in Nigeria and is fast replacing other traditional local staples in the country (Oyelere, 2020).

Cassava is important not only as a food crop but even more as a major source of income for rural households. As an income crop, cassava generates cash income for the largest number of households' comparison with other staples in the same category (Sanusi *et al.*, 2020). Tropical farmers produce 233 million tons of cassava on 18.6 million hectares (Sajeev *et al.*, 2021). A total of 40 countries in Africa make up more than 50% of the production, while Asia and Latin America contribute 34% and 15%, respectively (Crippa *et al.*, 2021). Although socioeconomic factors, market conditions and abiotic constraints negatively

affect cassava production, pests and diseases are well known to substantially reduce yields, resulting in multi-billion dollar crop losses (Pathak, 2019; Blesh *et al.*, 2023). According to FAO (2018), cassava is a choice crop for rural development, poverty alleviation, economic growth and ultimately food security (Adebayo and Silberberger, 2020; Adu *et al.*, 2023).

Although Africa is the world's largest cassava producer with 169 million tones (61% of global production), the average yield is paradoxically the lowest at 9 tones/ha compared to Asia with a yield of 21.5 t/ha (FAOSTAT, 2019). Latest report as at 2017 shows that Nigeria is the largest producer of cassava in the world with 59 million tons of tuberous root production, representing about 20% of global production (Otekunrin *et al.*, 2021; International Institute of Tropical Agriculture (IITA), 2021).

The steady increase in the world population and changes in climate are adding pressure to agriculture as the need to produce more food intensifies. Increase in temperature is also anticipated to result in increased abundance of many insect pests through higher rates of growth and population development as well as their spread and migration (Skendžić *et al.*, 2021). Great efforts are therefore being put into enhancing the management of emerging pests and diseases along with the production of climate-resilient and disease-resistant crops in these regions in an attempt to reduce the risk of hunger (FAO *et al.*, 2018; Mrisho *et al.*, 2020; Osumba *et al.*, 2021).

Some of these diseases that attack cassava are cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) both largely propagated through the exchange of infected planting materials among farmers, and resulting in losses of over 1 billion USD annually (Amelework and Bairu 2022) and resulting to about N100 billion (approximately 250 million USD) loss in Nigeria. Currently,



CBSD is restricted to East and Central Africa and has not been reported in any West African country (Ferguson *et al.*, 2019; Chen *et al.*, 2019).

However, reports of the spread of previously localized virulent strains of CMD to new regions raises concern and necessitates the need for urgent interventions to minimize this trend and ensure continued exclusion of the devastating CBSD from West Africa and/or ensure that the disease is promptly recognized, reported and effectively contained should it be inadvertently introduced into the region (Eni *et al.*, 2019). Cassava viral diseases are among the major constraints currently affecting cassava producers' production in Nigeria (Otero, 2022), for this, adoptions of agricultural technologies are widely prioritized.

To reduce these losses, several disease management methods such as planting resistant varieties, planting improved variety, Roguing, good agronomic practices and biological control methods have been recommended by WAVE since 2014 through series of campaigns which has been conducted by the Central and West African Virus Epidemiology in Nigeria and in the member countries in Central and West Africa

Agricultural technology is among the most changeable and impactful areas of modern technology, driven by the fundamental need for food and for feeding an ever-growing population. The adoption of agricultural technologies enables improvement in agricultural productivity and also reduces poverty by increasing the income and consumption of farm households. Moreover, the adoption of agricultural technology increases production for home consumption and reduces food prices, which encourages more food consumption (De Janvry *et al.*, 2017). Given that, various studies that were conducted at the country and regional levels

have confirmed the poverty reduction effect of the adoption of agricultural technologies. For example, Asfaw *et al.* (2012), Zeng *et al.* (2014), Sebsibie *et al.* (2015), and Jaleta *et al.* (2015), Shita *et al.* (2018, 2020), Teka and Lee (2020), Biru *et al.* (2020), Chirota (2020), Feyisa and Yildiz (2020), Ayenew *et al.* (2020), Tamirat and Abafita (2021), and Wordofa *et al.* (2021) have conducted a study on the impact of agricultural technology adoption on smallholder farmer's welfare and found that the adoption has significantly raised production and productivity, household income, nutrition, consumption expenditures. Thus, this study is inspired to gain more insight into how the adoption of agricultural technologies can increase household food security and reduce poverty in the North West and North East region, Nigeria. Household dietary diversity was employed in this study to measure food security. HDD measures the number of different food groups consumed over a given reference period (FAO, 2013). HDD reflects the economic ability of the household to access a variety of foods (Swindle and Bilinsky, 2006; Leroy *et al.*, 2015). HDD is strongly associated with other measures of food security (FAO, IFAD and WFP, 2013; Hoddinott, 2012) and it is an efficient measure that has been widely utilized to measure food security (FAO, 2015; Headey and Ecker, 2013). The food groups selected to establish HDD were categorized into 12 food groups following Swindle and Bilinsky (2006). The identified food items used to compute HDD include; cereals, roots and tubers, vegetables, fruits, meat, eggs, fish and shellfish, legumes, seeds and nuts, milk and milk products, oils and fats, sugar, condiments, and beverages (FAO, 2013).

The contribution of this paper to the existing literature is three fold. First, some studies focused on the determinants of agricultural technology adoption in the region and the

country, for instance (Feyisa & Yildiz, 2020; Kelemu, 2015; Tefera et al., 2016). However, this study examines both the determinant and implied impacts of adopting WAVE-CDMTs on food security. Second, many studies that were conducted in the area focused on other crops than cassava (for example; Ahmed, 2015; Natnael, 2019; Shako et al., 2021). Third, most previous studies have applied, double-hurdle, ordered probit, OLS, Tobit, and PSM estimation techniques, to estimate the impacts on the outcome variable, for example (Hagos, 2016; Mulugeta & Hundie, 2012; Siyum et al., 2021; Tesfaye et al., 2016; Sebsibie et al., 2015; Shita et al., 2020; Tamirat & Abafita, 2021; Teka & Lee, 2020; Wordofa et al., 2021). However, these models are subject to self-selection bias, inadequate counterfactuals, and endogeneity problems, which do not clearly show the effect of adoption on the outcome variables (Belay & Mengiste, 2021; Biru et al., 2020; Kassie et al., 2018). In addition, these methods assume that selection bias due to unobservable factors is only marginal; while in non-experimental studies of this kind, evaluating the impact is challenging mainly because of selection bias due to both observable and unobservable factors (Belay & Mengiste, 2021; Kassie et al., 2018). In this regard, this study employed an endogenous switching regression model, which accounts for all the impact evaluation challenges. Finally, there is no study conducted on the impact of WAVE-CDMTs adoption on food security in the study area. Therefore, the objective of this study is to examine the impact of WAVE-CDMTs adoption on food security in the North West and North East Region, Nigeria.

Methodology

Description of the study area

This study was conducted In North West and North East, Nigeria.

North West and North East: North West and North East parts of Nigeria encompasses 13 states with a combined population of approximately 70 million people. The regions are characterized by diverse geographical features, including savannas, grasslands and semi-arid savannas. The predominately muslim population comprises of various ethnic groups, including Hausa, Fulani and Kanuri. Agriculture and trade are significant economic activities, with mineral resources also present. Figure 1 present a map of the study area.

Data and sampling description

A Multi- stage sampling was used for this study to select the study states and sample. Four states from each of the two geo political zones were purposively selected based on the active WAVE activities on cassava diseases managements in the areas. A purposive selection of one LGA from each senatorial zone of each state based on the intensity of cassava production and because of the active WAVE activities on cassava diseases managements in the areas of the zones. Reconnaissance survey was conducted to identify registered participating cassava farmers of WAVE in the States. This was carried out with the assistance of Nigeria Cassava Growers Association (NCGA) and Agricultural Extension Agents. A random selection of 257 WAVE Beneficiaries which was determined by Yamane (1973) method of sample size determination. In order to effectively study the impact of cassava diseases management technologies on adopters, non- adopters was used as a control group for comparative analysis where (264)non-WAVE Beneficiaries were selected randomly. In all, (528) cassava farmers were randomly selected. However, upon data collection, it was revealed that both groups (WAVE Beneficiaries and Non- WAVE Beneficiaries) contained adopters and non-

adopters. Therefore, the final sampling structure consisted of four groups: beneficiaries who adopted, beneficiaries who did not adopt, non-beneficiaries who adopted and non-beneficiaries who did not adopt. In all, the study comprise of (237) adopters and (299) non-adopters, making a total of 536 sample size.

Methods of data collection

Cross-sectional data was used for meeting the objectives of this study. The data was collected from both primary and secondary sources. Primary data was collected from Adopters and non-adopters, using structured questionnaire (Kobo collect) with the assistance of extension agents from WAVE project, this serves to support data gathered through the use of questionnaires. Before the real data collection, the questionnaire was pretested for further fine-tuning. In addition, orientation was given for enumerators to have a common understanding regarding the data collection instrument. Finally, the questionnaire was administered by trained enumerators in close supervision of the researcher.

Methods of data analysis

After the data collection, for data analysis, the researchers have employed both descriptive and econometric methods. The descriptive analysis includes mean and standard deviation and is mainly used to obtain a better understanding of the household demographic features, socio economic, and institutional features of the farmers. From the econometric methods, a multinomial endogenous switching regression model is employed to scrutinize the impact of adoption of WAVE-CDMTs on food security of smallholder farmers in North West and North East, Nigeria.

Endogenous switching regression(ESR)

In measuring the Impact of Cassava Diseases Management Technologies on food security of Smallholder Farmers in Northwest and Northeast, Nigeria, the study applied endogenous switching regression model. The efficient technique to determine endogenous switching regression (ESR) model is employing the full information maximum likelihood (FIML) estimation (Lokshin and Sajaia, 2004). Lokshin and Sajaia (2004) have demonstrated other methods of estimating ESR such as the two stage least squares (2SLS) and the maximum likelihood estimation which can be used by fitting one regression equation at a time. These techniques are less efficient compared to the full information maximum likelihood (FIML) which depends heavily on joint normality of the error terms that makes the model estimator more efficient. They require very hard and complicated modifications in determining consistent standard errors. They also reveal impecunious accomplishment in scenarios of high multicollinearity between the covariates and the selection model (Maddala, 1983). The specification of the model that was used here is adapted from the works of Wu F (2022). The endogenous switching regression model is estimated in two stages. Thus, the first step of the two-step endogenous switching regression model (ESRM) entailed modelling household's binary choice to adoption employing the probit model that is structurally expressed below;

$$Y_i = X_i\beta_i + A_i + \varepsilon_i \dots\dots\dots (4)$$

In the formula (4), Y_i is a binary indicator for agricultural technology adoption for household in period such that; 1=adoption, 0=otherwise;; X_i is the vector of individual, family and farm characteristics (such as age, education, family size, farm size, etc.) that may affect farm

performance indicators; A_i are the vector of explanatory variables; ε_{ia} is a random disturbance term.

The second step was the estimation of the two probit regressions explaining the two outcome variables of each group of households in the two regimes (adopters and non-adopters).

Therefore, the household food security and equations on the adoption choice are expressed in an endogenous switching regression model as presented below;

Regime

$$Y_{ia} = X_{ia}\beta_a + \sigma_{\mu a}\lambda_{ia} + \varepsilon_{ia}, \text{ if } A_i = 1 \dots \dots \dots (5)$$

$$Y_{in} = X_{in}\beta_n + \sigma_{\mu n}\lambda_{in} + \varepsilon_{in}, \text{ if } A_i = 0 \dots \dots \dots (6)$$

In formulas (5) and (6), Y_{ia} and Y_{in} respectively refer to the outcome indicator of household with and without adopting the technology. In addition, X_{ia} and X_{in} indicate the factors that Actual expectations observed in the sample:

$$E\left(\frac{Q_{ik}}{j} = k\right) = \beta_k Zki + \sigma_k \lambda k \dots \dots \dots (7a)$$

$$E\left(\frac{Q_{i1}}{j} = 1\right) = \beta_1 Z1i + \sigma_1 \lambda 1 \dots \dots \dots (7b)$$

Counterfactual expected outcomes (not observed in the sample):

$$E\left(\frac{Q_{ik}}{j} = 1\right) = \beta_1 Zki + \sigma_1 \lambda k \dots \dots \dots (7c)$$

$$E\left(\frac{Q_{i1}}{j} = K\right) = \beta_k Z1i + \sigma_k \lambda 1 \dots \dots \dots (7d)$$

The average treatment effect on the treated (ATT) will be calculated as the difference between eq. (7a) and eq. (7c); and specified as:

$$ATT = E\left(\frac{Q_{ik}}{j} = k\right) - E\left(\frac{Q_{ik}}{j} = 1\right) = Zki(\beta_k - \beta_1) + \lambda k(\sigma_k - \sigma_1) \dots \dots \dots (8)$$

Similarly, the average treatment effect on the untreated (ATU) will be the difference between equation (7b) and equation (7d) and can be specified as:

$$ATU = E\left(\frac{Q_{i1}}{j} = 1\right) - E\left(\frac{Q_{i1}}{j} = k\right) = Z1i(\beta_k - \beta_1) + \lambda k(\sigma_k - \sigma_1) \dots \dots \dots (9)$$

The difference between eq. (4) and eq. (5) provides in transitional heterogeneity (TH) that shows whether the effect of adoption is higher or lower for the adopters than the non-adopters.

affect the outcome of the two types of family farms, ε_{ia} and ε_{in} both represent random disturbance items. The correlation coefficients of ε_{ia} , ε_{in} and μ_i were 1 and 0 respectively.

Conditional expectations and treatment effects of adoption

The endogenous switching regression model was used to compute both the average treatment effect on the treated (ATT) and the untreated (ATU). This can be done by a simple comparison of the expected values of the outcome of the treated (adopters) and untreated (non adopters) in actual and counterfactual situations. Following, Kassie *et al.*, (2018), and Zegeye *et al.*, (2022), the conditional expectations for the outcome variables in both the observed and their counterfactual scenarios can be specified as follows:

Empirical Results

In this section, we present the econometric results on the determinants of adoption and the impact of the adoption of CDMTs on food security of family farms in North West and North East, Nigeria based on cross-sectional data available using endogenous switching regression model (ESR) as provided in the table below.

Determinants of adoption of CDMTs and determinants of Household food security

Table 1, shows the results of the ESR model estimation of the impact of the adoption of CDMTs on household dietary diversity of family farms. The likelihood ratio test and correlation coefficients of the covariance terms between the error terms in decision and outcome equations also have important economic interpretations (Fuglie and Bosch, 1995). The results of likelihood ratio test for joint independence of the adoption and outcome equations were significant, suggesting that the adoption and outcome equations are jointly dependent. In addition, the correlation term ρ in the adopter's equation is negative and significantly non zero, indicating that there is a sample selection bias caused by unobservable factors. Failing to account for these factors may result in biased estimates which may lead to an underestimation of the impact of the CDMTs. The HDD function of the households that adopted is significantly different from the HDD function of households that did not adopt.

The results of the first stage estimation of the ESR model regression, show the determinants of the adoption of CDMTs in family farms. For North West, the results in Table 1 shows that the coefficient of education is positive and significant at 10% level. This implies that having an educated household head increases the chance of adopting and also a year increase

of the education of household head increases the adoption of CDMTs in the study area. Better education enables farmers to be aware of the benefits of CDMTs and motivate them to adopt them. This finding is consistent with Wudu (2017), Tamirat et al. (2020) and Zegeye et al. (2022).

The coefficient of farm size is positive and significant for the adoptions of CDMTs at 10% level, showing that having a large farm size increases the probability of adopting the technologies. The possible explanation is that farm households who have large farm size can produce more than household consumption and the surplus amount of production is sold and this generates a certain amount of cash that can be used to purchase agricultural inputs. The finding is consistent with (Wudu, 2017) and Zegeye et al. (2022).

The estimated coefficient of farming experience was found to be positive, reflecting positive effect on likely of adoption decision of CDMTs in the study area. This result implies that farmers, who have more farming experience, are most likely to adopt CDMTs, keeping the effects of other variables constant. This is supported by the obtained statistically significant coefficient at 10% probability level, which confirms the logical association between producing any crop and the level of farming experience owned by smallholder farmers. This is in line with the findings by Bayissa, 2014 and Fadeyi et al., 2022.

As expected, the coefficient of distance to market center has a negative and significant relationship (at 10% level) with probability of adoption decision of CDMTs in the study area. This implies that households that live near to the market places are likely to adopt the technologies than those who live far from the market place. Since farmers may possibly have higher access to information on new or improved farm technologies, information on input (output) prices, and also could lead to

timely adoption, and lower production cost. This is in line with the results of (Bayissa, 2014; Wudu, 2017; Belay & Mengiste, 2021; Zegey *et al.*, 2022).

As expected, the coefficient for the extension visit positively and significantly affects the adoption of CDMTs at 10% level, meaning that farmers who have an extension visit during their adoption practice of agricultural technologies are more likely to adopt farm technologies than their counter parts. This is because that extension agent assists the farm households to get the required information (characterization), application, and benefits of agricultural technologies. The result is similar with (Hagos *et al.*, 2016; Wudu, 2017 and Zegeye *et al.*, 2022).

The coefficient of farmers who have participated in WAVE training are positive and significant at 5% level, this implies that household heads who participated in the training are more likely to adopt CDMTs. This is because training experience as a way of

education, by imparting experience to farmers, let farmers understand and master the use and economic value of new technology, and promote the adoption of new technology by farmers. This finding is consistent with findings of (Wu, 2022).

The coefficient of farmers who have participated in WAVE demonstration plots are positive and significant at 5% level, this implies that household heads who participated in the field demonstration are more likely to adopt CDMTs. The result suggests that, on farm demonstrations are means of learning by doing which enable farmers to develop confidence on the given technology. In addition, demonstration plots will create the opportunity for experience sharing among invited and host farmers of the demonstration plots. This result is consistent with Negussie *et al.*, (2022); Yigezuet *et al.*, (2018) who find out that both hosting and involvement on-farm demonstration trials decreases the duration to adoption by 36.5%.

Table 1 Impact of the adoption of CDMTs on the household food security: Estimated by the ESR model.

Variables	North West			North East		
	Adoption of CDMTs	Adopters	Non adopters	Adoption of CDMTs	Adopters	Non adopters
Age	-0.004 (0.010)	-0.016 (0.025)	-0.005 (0.017)	-0.010 (0.010)	-0.004 (0.011)	0.143 (0.250)
Educational level	0.047* (0.025)	2.617*** (0.871)	1.246** (0.552)	0.043* (0.022)	0.044* (0.025)	2.400** (0.937)
Household size	-0.011 (0.027)	0.051 (0.062)	0.032 (0.042)	0.008 (0.023)	0.116*** (0.020)	-0.069 (0.204)
Farm size	0.045* (0.022)	0.194** (0.091)	0.086* (0.046)	-0.026* (0.015)	0.08992** (0.030)	0.275 (0.513)
Cassava farming exp	0.026* (0.014)	0.177*** (0.053)	0.077* (0.042)	0.028* (0.015)	0.191*** (0.015)	0.216 (0.261)
Farm distance	-0.023* (0.013)	-0.012 (0.102)	-0.058 (0.041)	-0.099** (0.041)	0.472*** (0.097)	-0.029 (0.021)
Extension contact	0.735* (0.293)	4.353 (2.569)	-2.411** (1.160)	0.2505* (0.138)	0.458* (0.211)	2.462 (5.902)
Caravan	0.342 (0.367)	1.805 (1.246)	1.261* (0.721)	0.600* (0.358)	0.313** (0.142)	10.247*** (3.171)
Training	0.993** (0.466)	7.651** (3.802)	2.960* (1.503)	0.966** (0.335)	1.977** (0.668)	16.707*** (4.216)
Demo plot	1.279** (0.471)	1.291** (0.636)	1.278* (0.793)	0.253* (0.131)	0.198*** (0.036)	9.340** (3.888)
Hired labour	-0.129 (0.259)	1.196 (1.752)	-0.522 (0.509)	-0.267 (0.293)	-0.085 (0.310)	2.514 (6.738)
Constant	0.457 (0.740)	14.588*** (3.727)	13.068*** (3.357)	5.58 (174.6)	8.021*** (0.903)	-7.773 (41.743)
Rho		-0.5320*** (0.038)	-		-0.0547*** (0.019)	-0.466*** (0.085)
Wald chi2	187.53***		0.3842*** (0.011)	99.67***		
LR test of indep. Eqns		chi2(1) = 22.87, Prob>chi2 = 0.0002			chi2(1) = 14.11, Prob>chi2 = 0.0000	
Number of obs.	254			282		

Source: Survey data (2023), Note: ***p < 0.01, **p < 0.05 and *p < 0.10.

The results of the second stage estimation of the ESR model show the determinants of family farm food security outcome (HDDS). As can be seen from the result in Table 1, there are significant differences in some variables coefficient estimates between the two types of family farms with and without the CDMTs. The result shows that variables like education, farm size, farming experience, participation in caravan, participation in training, participation in Demonstration plot and off farm activities are significantly associated with food security (HDDS) in the study area. From the estimated results in Table 1, it can be seen that regardless of whether CDMTs are adopted, the coefficient of education level had positive and significant effect on household dietary diversity at 1% and 5% level for adopters and non-adopters respectively, which shows that with the improvement of farmers' human capital, it is helpful to improve their household food security. This finding is consistent with Seng (2016): Zegeye et al. (2022): Kipkorir et al., (2023). On the contrary, the result disagrees with the findings of Dube and Ozkan (2022). The coefficient of farm size is positive and significant at 5% and 1% level for adopters and non-adopters respectively, this shows that Land size improved the HDDS among adopters and non adopters This reveals that more landholdings positively influence household food security. Households with large lands are less likely to be food insecure since they can minimize their production risks and increase productivity. The finding is consistent with (Zegeye et al. (2022: Kipkorir et al., 2023: Dube and Ozkan (2022). It can be seen that regardless of whether CDMTs are adopted, the coefficient for farming experience is positive and significant at 10% and 1% level for adopters and non-adopters respectively, this shows that with the improvement of farmers' social capital, it is helpful to optimize large scale operations there

by improve their household food security and also experienced farmers learn from their mistakes, adapt to changing conditions and refine their practice. The finding is consistent with(Wu, 2022).

It can also be seen that the coefficient of Participation in WAVE awareness program (caravan) is significantly positive at 5% level for non-adopters. This shows that farmers who participated in caravan tend to have improved household dietary diversity. This means that participation in training enhances farmers' knowledge and skill leading to improved household food security, participation in training also fosters relationship among farmers, promote information exchange and collaboration. The finding is consistent with(Wu, 2022)

It can also be seen that regardless of whether CDMTs are adopted the coefficient of participation in WAVE training is significantly positive at 5% and 10% level for adopters and non-adopters respectively. This means that training enhances farmers' knowledge and skill leading to improved yield and income thereby leading to improve household food security, participation in training also fosters relationship among farmers, promote information exchange and collaboration. The finding is consistent with(Wu, 2022)

It can also be seen that the coefficient of participation in WAVE demonstration plot is significantly positive at 5% and 10% level for adopters and non-adopters respectively. This shows that farmers who participated in field demonstration tend to have improved household dietary diversity. This means that training enhances farmers' knowledge and skill leading to improved household food security. The result suggests that, on farm demonstrations are means of learning by doing which enable farmers to develop confidence on the given technology. In addition, demonstration plots will create the opportunity

for experience sharing among invited and host farmers of the demonstration plots. This result is consistent with Negussie *et al.*, (2022); Yigezuet *et al.*, (2018) who find out that both hosting and involvement on-farm demonstration trials increase their outcome.

For North East, the results of the first stage estimation of the ESR model regression, show the determinants of the adoption of CDMTs in family farms. For North West, the results in Table 1 shows that the coefficient of education is positive and significant at 10% level. This implies that having an educated household head increases the chance of adopting and also a year increase of the education of household head increases the adoption of CDMTs in the study area. Better education enables farmers to be aware of the benefits of CDMTs and motivate them to adopt them. This finding is consistent with Wudu (2017), Tamirat *et al.* (2020) and Zegeye *et al.* (2022).

The coefficient of farm size is positive and significant for the adoptions of CDMTs at 10% level, showing that having a large farm size increases the probability of adopting the technologies. The possible explanation is that farm households who have large farm size can produce more than household consumption and the surplus amount of production is sold and this generates a certain amount of cash that can be used to purchase agricultural inputs. The finding is consistent with (Wudu, 2017) and Zegeye *et al.* (2022).

The estimated coefficient of farming experience was found to be positive, reflecting positive effect on likely of adoption decision of CDMTs in the study area. This result implies that farmers, who have more farming experience, are most likely to adopt CDMTs, keeping the effects of other variables constant. This is supported by the obtained statistically significant coefficient at 10% probability level, which confirms the logical association between producing any crop and the level of

farming experience owned by smallholder farmers. This is in line with the findings by Bayissa, 2014 and Fadeyi *et al.*, 2022.

As expected, the coefficient of distance to market center has a negative and significant relationship (at 5% level) with probability of adoption decision of CDMTs in the study area. This implies that households that live near to the market places are likely to adopt the technologies than those who live far from the market place. Since farmers may possibly have higher access to information on new or improved farm technologies, information on input (output) prices, and also could lead to timely adoption, and lower production cost. This is in line with the results of (Bayissa, 2014; Wudu, 2017; Belay & Mengiste, 2021; Zegeye *et al.*, 2022).

As expected, the coefficient for the extension visit positively and significantly affects the adoption of CDMTs at 10% level, meaning that farmers who have an extension visit during their adoption practice of agricultural technologies are more likely to adopt farm technologies than their counter parts. This is because that extension agent assists the farm households to get the required information (characterization), application, and benefits of agricultural technologies. The result is similar with (Hagos *et al.*, 2016; Wudu, 2017 and Zegeye *et al.*, 2022).

The coefficient of farmers who have participated in WAVE awareness program (Caravan) are positive and significant at 10% level, this implies that household heads who participated in the caravan are more likely to adopt CDMTs. This is because training experience as a way of education, by imparting experience to farmers, let farmers understand and master the use and economic value of new technology, and promote the adoption of new technology by farmers. This finding is consistent with findings of (Wu, 2022).

The coefficient of farmers who have participated in WAVE training are positive and significant at 5% level, this implies that household heads who participated in the training are more likely to adopt CDMTs. This is because training experience as a way of education, by imparting experience to farmers, let farmers understand and master the use and economic value of new technology, and promote the adoption of new technology by farmers. This finding is consistent with findings of (Wu, 2022).

The coefficient of farmers who have participated in WAVE demonstration plots are positive and significant at 10% level, this implies that household heads who participated in the field demonstration are more likely to adopt CDMTs. The result suggests that, on farm demonstrations are means of learning by doing which enable farmers to develop confidence on the given technology. In addition, demonstration plots will create the opportunity for experience sharing among invited and host farmers of the demonstration plots. This result is consistent with Negussie *et al.*, (2022); Yigezuet *et al.*, (2018) who find out that both hosting and involvement on-farm demonstration trials decreases the duration to adoption by 36.5%.

The results of the second stage estimation of the ESR model show the determinants of family farm food security outcome (HDDS). As can be seen from the result in Table 1, there are significant differences in some variables coefficient estimates between the two types of family farms with and without the CDMTs. The result shows that variables like education, farm size, farming experience, participation in caravan, participation in training, participation in Demonstration plot and off farm activities are significantly associated with food security (HDDS) in the study area. From the estimated results in Table 1, it can be seen that regardless of whether CDMTs are adopted, the coefficient

of education level had positive and significant effect on household dietary diversity at 10% and 5% level for adopters and non-adopters respectively, which shows that with the improvement of farmers' human capital, it is helpful to improve their household food security. This finding is consistent with Seng (2016); Zegeye *et al.* (2022); Kipkorir *et al.*, (2023). On the contrary, the result disagrees with the findings of Dube and Ozkan (2022)

The coefficient of farm size is positive and significant at 5% level for adopters, this shows that Land size improved the HDDS among adopters. This reveals that more landholdings positively influence household food security. Households with large lands are less likely to be food insecure since they can minimize their production risks and increase productivity. The finding is consistent with (Zegeye *et al.* (2022); Kipkorir *et al.*, 2023; Dube and Ozkan (2022). It can be seen that the coefficient for farming experience is positive and significant at 1% level for adopters. This shows that for every additional unit in years farming experience, the outcome variable increases by the coefficient value, holding all other variables constant. This implies that with the improvement of farmers' social capital, it is helpful to optimize large scale operations there by improve their household food security than their counterparts and also experienced farmers learn from their mistakes, adapt to changing conditions and refine their practice. The finding is consistent with (Wu, 2022)

It can also be seen that the coefficient of Participation in WAVE awareness program (caravan) is significantly positive at 5% and 1% level for adopters and non-adopters. This shows that farmers who participated in caravan tend to have improved household dietary diversity. This means that participation in training enhances farmers' knowledge and skill leading to improved household food security, participation in training also fosters

relationship among farmers, promote information exchange and collaboration. The finding is consistent with(Wu, 2022)

It can also be seen that regardless of whether CDMTs are adopted the coefficient of participation in WAVE training is significantly positive at 5% and 1% level for adopters and non-adopters respectively. This means that training enhances farmers’ knowledge and skill leading to improved yield and income thereby leading to improve household food security, participation in training also fosters relationship among farmers, promote information exchange and collaboration. The finding is consistent with(Wu, 2022)

It can also be seen that the coefficient of participation in WAVE demonstration plot is significantly positive at 1% and 5% level for adopters and non-adopters respectively. This shows that farmers who participated in field demonstration tend to have improved household dietary diversity. This means that training enhances farmers’ knowledge and skill leading to improved household food security. The result suggests that, on farm

demonstrations are means of learning by doing which enable farmers to develop confidence on the given technology. In addition, demonstration plots will create the opportunity for experience sharing among invited and host farmers of the demonstration plots. This result is consistent with Negussie *et al.*, (2022); Yigezuet *et al.*, (2018) who find out that both hosting and involvement on-farm demonstration trials increase their outcome.

Impact of CDMTs adoption on household food security: Estimating average treatment effects of CDMTs

Table 2 presents the impact of the adoption of CDMTs on cassava farmers Food security, which is calculated by comparing the expected HDDS of the family farm (a) with the new technology and (b) without the new technology. In addition, we intend to compare the family farms with new technology if they do not adopt (c) and the family farms without new technology if they adopt (d), namely the expected income under the actual situation and the counterfactual conditions

Table 2. Average Treatment Effect of the Impact of CDMTs Adoption on Household Food Security.

Food security (HDDS)	Mean Outcome		ATT	ATU	ATH
	Adopters	Non adopters			
North West	(a)8.0543	(c)6.2815	1.7728 (0.041)***	1.6200 (0.048)***	0.1528 (0.035)***
	(d)6.8868	(b)5.2668			
	(0.051)	(0.053)			
North East	(a)8.0891	(c)6.7982	1.2909 (0.045)***	1.8633 (0.040)***	-0.5724 (0.032)***
	(d)7.3054	(b)5.4421			
	(0.016)	(0.038)			

Notes: TT = Adoption effect for adopters, TU = Adoption effect for non-adopters, TH (TT-TU) = transitional heterogeneity, Values in parentheses(Standard errors),*Significant at the 10% level, ** significant at 5%, and *** significant at 1% level.

For North West, the results in Table 2 shows that the actual household dietary diversity for the households who adopted was 8.0543 counts while the household dietary diversity would have been 6.2815 counts had the households decided not to adopt. This implies that household food security would have fallen by 1.7728 counts had the households decided not to adopt CDMTs.

On the other hand, the households that did not adopt CDMTs had a household dietary diversity of 5.2668 and if they had adopted, the household dietary diversity would have been 6.8868. Thus, adoption of CDMTs would have improved the non-adopters households dietary diversity by 1.6200 counts. This means that households deciding to adopt CDMTs are a key income source in improving household food security since income increases dietary diversity by expanding the purchasing power and affordability of the households (Seng, 2016)

The transitional heterogeneity effect is positive for HDDS implying that the effect was greater for farm households that actually adopted relatively to those households that did not adopt. To sum up, the results of the study validate that the adoption of CDMTs significantly increased farmers household food security than non-adoption. This finding is in line with the previous work of (Seng 2016: Dube and Ozkan, 2022: Setsoafa *et al.*, 2022: Kipkorir *et al.*, 2023: Amankwah and Gwatidzo, 2024). As a consequence, a basic policy implication is that family farms that do not adopt new technologies should be encouraged to adopt new technologies at present.

For North East, the results show that the actual household dietary diversity for the households who adopted was 8.0891 counts while the household dietary diversity would have been 6.7982 counts had the households

decided not to adopt. This implies that household food security would have fallen by 1.2909 counts had the households decided not to adopt CDMTs.

On the other hand, the households that did not adopt CDMTs had a household dietary diversity of 5.4421 and if they had adopted, the household dietary diversity would have been 7.3054. Thus, adoption of CDMTs would have improved the non-adopters households dietary diversity by 1.8633 counts. This means that households deciding to adopt CDMTs are a key income source in improving household food security since income increases dietary diversity by expanding the purchasing power and affordability of the households (Seng, 2016)

The transitional heterogeneity effect is negative for HDDS implying that the effect was greater for farm households who had not adopted relatively to those households that have actually adopted if they has not adopt. To sum up, the results of the study validate that the adoption of CDMTs significantly increased farmers household food security than non-adoption. This finding is in line with the previous work of (Seng 2016: Dube and Ozkan, 2022: Setsoafa *et al.*, 2022: Kipkorir *et al.*, 2023: Amankwah and Gwatidzo, 2024). As a consequence, a basic policy implication is that family farms that do not adopt new technologies should be encouraged to adopt new technologies at present.

Conclusion and recommendation

This study examines the impact of Cassava disease management technologies (CDMTs) adoption on food security of smallholder farmers in North West and North East, Nigeria. The study utilizes cross-sectional data collected in 2023 from a randomly selected sample of 536 households (254 in North West and 282 in North East) using structured questionnaire (kobo collect) and employed the



ESR model to estimate simultaneously the selection equation and outcome equation. The results of the study can be concluded as follows: first, it shows that farm households' decision to adopt CDMTs are significantly determined by the education level of the household head, household size, farm size, farming experience, extension contact, distance to market, participation in WAVE caravan, participation in WAVE training and participation in WAVE demonstration plot. Second, the outcome equations (food security) of adopters and non-adopters is significantly determined by the education level of the household head, household size, farm size, farming experience, participation in WAVE caravan, participation in WAVE training and participation in WAVE demonstration plot. Third, the average treatment effect of adoption on the outcome equations (food security) is significantly higher for adopters than their counterparts. Also, the non-adopters significantly would have higher yield, income and food security if they had been adopters. Thus, the study confirmed that the adoption of CDMTs has a positive impact on increasing food security. This suggests that there is huge potential of adopting agricultural technologies on increasing household's food security and thereby improving rural household welfare. From a policy perspective, this study recommends policies that aim to encourage and expand the adoption of CDMTs that will have a significant impact on improving household yield and livelihood, thus reducing poverty in the region and Africa. Specifically, the regional and the federal government should strengthen the policy interventions and expand access to agricultural extension services since access to extension positively influenced the adoption of CDMTs. This is very essential to provide information about the use and benefit of modern agricultural technologies. It will also allow farmers to seek advice from the

agricultural sector experts to make the best of these technologies to minimize the risk of adoption due to inadequate information transfer.

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