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Drivers of Vitamin-A bio-fortified potato production under climate change stress: smart adaptation practices among smallholder farming in Kogi state, Nigeria

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Abstract

The study examined the drivers of sustainability of Vitamin-A bio-fortified potato production under climate change stress using smart agricultural adaptation practices among farmers in Ankpa LGA of Kogi State, Nigeria. Specifically, it described the socio-economic characteristics of respondents, assessed their awareness of climate change, outlined adaptation practices, and estimated how these adaptation practices and institutional factors affect the adoption and use of Vitamin A biofortified potato production. A multi-stage sampling technique was used to select 240 respondents. Data were collected through structured questionnaires and analyzed using descriptive and inferential Statistics. The results of the socioeconomic characteristics showed that 46.3% of the respondents were aged between 36 and 50 years and dominated the production, while 8.8% were between the active age group of 21 and 35 years. Male farmers accounted for 72.5%, and 87.5% were married. Most (87.5%) of the respondents had formal education. A small proportion (25.2%) had access to extension services and credit. The results of the awareness of climate change showed that not all the respondents were aware of adaptation practices. There was a significant difference ($p<0.001$) in annual output between those who adopted adaptation practices and those who did not. Probit regression analysis indicated that the use of adaptation practices influenced the adoption of Vitamin A potatoes. All adaptation methods had a positive and significant effect ($p < 0.05$) on the adoption and use of the crop. Credit and extension services were essential for effective Vitamin-A potato production in the area.

Key words: Sustainability, Vitamin-A potato production, smart adaptation practices, Kogi state

Background: Eradication of chronic hunger and poverty is among the Sustainable Development Goals of the United Nations' SDGs 1 and 2 (Food and Agriculture Organization of the United Nations, FAO, 2015). Chronic hunger encompasses a lack of protein (kwashiorkor), a combination of protein and energy deficiency (marasmus), or a deficiency in micronutrients such as vitamins and minerals (hidden hunger syndrome). Generally, there is widespread hunger and poverty in developing regions like sub-Saharan Africa (SSA), with about 214 million people trapped in chronic hunger and poverty (Nazmul, et al., 2021). However, the effects of climate change are exacerbating the world's poverty level, particularly the hidden hunger component. Rising temperatures and altered precipitation patterns significantly impact crop yield and nutrient density (Thompson & Garcia, 2022). Crops are a major source of vitamin A in many developing countries, and there has been a decline in beta-carotene content when they are grown under heat stress conditions (Anderson et al., 2021). Efficient irrigation systems and water conservation techniques have shown promising results in maintaining vitamin A levels in crops. Emerging techniques such as vitamin A potato bio-fortification and precision agriculture offer enhanced opportunities for maintaining nutrient levels. Such successes will require continued research and development of locally adapted solutions for rural households (Martinez et al., 2021).

Bio-fortified orange sweet potato (OSP) is an extremely rich source of provitamin A that has been proven to improve the vitamin A status in children and reduce the likelihood and duration of diarrhea. Children with vitamin A deficiency (VAD) are at increased risk of severe morbidity from common childhood infections such as diarrhea and measles. In extreme deficiency, they could become blind. Vitamin A is highly essential in sub-Saharan Africa (SSA), where more than 43 million children are Vitamin A deficient, resulting in approximately 6 million deaths annually (Adewumi et al., 2019). Sweet potatoes that are provitamin A can provide up to 100% of daily Vitamin A requirements and contribute to a reduction in VAD in regions where daily sweet potato consumption is high. Generally, Potatoes are a crop consumed in all parts of Nigeria in different forms, which include fried, boiled, roasted, and used as sweeteners in pure natural drinks like "kunu", or "'obiolo". According to Anderson et al, (2021), sweet potatoes contain high concentrations of biologically active compounds that may hold significant medicinal value for certain human diseases. Sweet potato is one of the most economically important crops for addressing global food insecurity and climate change issues under conditions of extensive agriculture (Martinez et al, 2020). More than 95% of the world's sweet potato crop is grown in developing countries. African farmers produce about 7 million tons of sweet potatoes annually, with Nigeria being one of the largest producers in sub-Saharan Africa, having annual production estimates of 4.03 million tons from an area of about 1.7 million ha and a yield of 2.3t/ha. In 2018, Nigeria accounted for approximately 1.3% of global potato production (Adewumi et al, 2018) and witnessed a steady output over the years with an annual growth rate of 3.5% between 2010 and 2019 (Adeyonu et al, 2019). Sweet potatoes are important for food security because they are early maturing and can be intercropped with other crops, such as yams and maize. It has a high yield potential, is resistant to production stresses, is environmentally friendly, and can be grown three times a year.

Despite these efforts, climate change poses a significant threat to crops, humanity and development, although its impact is not uniform across communities, countries, and regions (Tarfa et al., 2019). Climate is one of the major factors affecting agricultural productivity directly or indirectly, as climate effects are linked to physiological processes (Adeagbo et al., 2023). As a result, climate change poses a severe threat to the agricultural system, food security, and human nutrition. In addition to the effects of climate change, SSA agriculture faces numerous challenges, including inadequate fertilizer, poor irrigation facilities, and limited access to improved seed varieties, all of which lead to low yields. There is also the issue of post-harvest losses resulting from inadequate storage facilities.

Consequently, the extent of damage from climate change is dependent on the ability to adapt (Tarfa et al., 2019). In an era where climate change is becoming increasingly apparent, adaptation in the agricultural sector has become more crucial (Kamakaula, 2024). According to Adeagbo et al. (2023), the adaptive capacity of the agricultural sector is the ability to adjust to climate change in order to avoid unforeseen damage and capitalize on opportunities to cope with the outcome. Some adaptation practices that help mitigate the impact of climate change among smallholder farmers include crop diversification, adoption of new crop types, biofortification of crops, use of improved crop varieties, and soil water management (Adeagbo et al., 2023). Climate-smart practices, as above, employ drought-resistant crop varieties that help farmers adapt, enhance crop productivity and mitigate the level of food insecurity among vulnerable smallholder farmers (Nazmul et al., 2021). Climate change mitigation has not received as much attention as climate change adaptation because mitigation requires many resources and technical skills, which are limited in developing countries like SSA (De Guisti et al., 2019). Though adaptation practices are promising in SSA, resource constraints hinder their effective implementation (Roberts, 2022). As a result, the future of vitamin A supply in a changing climate will likely depend on an integrated approach combining multiple adaptation approaches and continued research and development of locally adapted solutions. Vitamin A bio-fortified potatoes have the potential to address the vitamin A-related hidden hunger problem in SSA and Nigeria in particular. However, the level of adoption and use of this product is dependent on awareness and the level of use of climate change adaptation options. The National Root Crop Research Institute, International Institute of Tropical Agriculture and other stakeholders in research and development have invested many resources in bio-fortification in cassava, potatoes and other crops and disseminated by national extension services over the years in Nigeria (Wossen et al., 2019). These products cater to the needs of smallholder farmers who are both producers and consumers of their own produce (Olaosebikana et al., 2019).

There is copious empirical literature on the adoption of improved crop varieties in Nigeria, which includes the study by Oyinbo et al. (2019) on maize, Manda et al. (2020) on cowpea, and Abdoulaye et al. (2014) on rice. However, there are insufficient empirical studies on how climate change adaptation practices affect the adoption and use of bio-fortified potato in Nigeria. This work is designed to fill this gap. The aim of the study was to assess the factors influencing the adoption and use of vitamin-A biofortified potato production by smallholder farmers in Kogi. The study was expected to provide information on the level of resilience in vitamin-A potato production in Nigeria. To achieve the aim of the study, the following questions were raised: What is the level of awareness of smallholder farmers on the climate change phenomenon? What are the socio-economic characteristics of the farmers (that would enable them to adopt climate change adaptation practices)? How do climate change adaptation practices affect the adoption of vitamin A potato products among smallholder farmers? And, was there difference in potato output for smart adaptation practices user and non-users?

Methodology: Study area: The study was conducted in Ankpa Local Government Area (LGA), Kogi State. The state is in north-central Nigeria within latitudes $5^0 30^I$N and $8^0 50^I$N and longitudes $5^0 51^I$E and $8^0 00^I$E. The state is referred to as “The Confluence State’ because it is the meeting point of the River Niger and the River Benue. The State covers an area of approximately 29,883 Km^2 and borders with nine states. The ethnic groups in the state are Igala, Ebira, and Okun. The state’s economy is primarily agrarian, with the majority of the population engaged in farming. Major crops include cassava, maize, yams, potatoes, rice, cashews, and the rearing of goats, sheep, chickens, etc.

Sampling techniques: The study employed a survey design during the 2024 cropping season. Multi-stage sampling technique was employed to sample respondents. At the first stage, five communities in Ankpa LGA were purposely selected because agriculture is an intensive activity in these communities. The communities included Ojede, Ikamekpo, Ogodo, Ojokodo and Ojogobi. A simple random technique was used to select 48 respondents from each of the communities, giving a total of 240 respondents for the study.

Data collection and analysis: Data were generated using a structured questionnaire. The data included socio-economic characteristics such as household income, educational level, age of the household head, years of farming experience, number of extension visits, and climate change adaptation practices. Data were analyzed using descriptive statistics for socio-economic characteristics, state of awareness of climate change adaptation practices using frequency and mean distribution, and inferential statistics, including a Probit model and analysis of variance (ANOVA).

Probit Model: Probit model was used to examine how climate change adaptation practices and certain socio-economic characteristics influenced the adoption and use of Vitamin-A-enriched potatoes in production activities. The adoption and use of Vitamin-A potatoes were indicated with a 'yes' =1 or a 'no' = 0, otherwise. Therefore, probit model can predict how socio-economic and climate change adaptation practices drives adoption and use of vitamin-A potato production in the study area. It is explicitly represented as:

Y is a binary outcome (yes (1) or No (0)) and X be independent variables

$$Y = \beta 0 + \beta 1\, X1 + \beta 2X2 \ldots \beta nXn + \varepsilon$$

Probability equation:

$$P(Y = 1) = \phi(Y*) = \phi(\beta 0 + \beta 1\, X1 + \beta 2X2 \ldots \beta nXn)$$

β_0 = constant

β_i = coefficients of probit covariates

Xi-Xn = covariates

X_1 = Farming experience (Years of farming)

X_2 = Educational level (Number of years in formal education)

X_3= Diversified crop production (Yes=1, no = 0),

X_4 = Grow drought resistant crops (Yes=1, 0 otherwise),

X_5 = Change planting dates? (yes=1, 0 otherwise),

X6 = Use water conservation practices (yes=1, 0 otherwise),

X_7= Use soil conservation techniques (yes=1, 0 otherwise),

X_8 = Make use of weather forecasting information (yes=1, 0 otherwise),

X_9 = Use insurance coverage (yes=1, 0 otherwise),

X_{10} = Access to credit (yes=1, 0 otherwise) and

X_{11} = Access extension services in your area (yes=1, 0 otherwise)

e = error term

and ϕ = Cumulative distribution function (CDF) of standard normal distribution

Results and Discussion: The results and discussion covered the socioeconomic characteristics of Vitamin A potato farmers, the level of awareness of climate change adaptation practices, number of adaptation practices adopted, the effect of adaptation practices on the farmers' choice on adoption and use of vitamin A potato and the effects of adaptation practices on the level of output.

Socioeconomic characteristics of the respondents: The socioeconomic characteristics of the respondents discussed include age, gender, marital status, educational background, number of years in formal education, major occupation, minor occupation, annual income, household size, farm size, years of growing potatoes, source of farm labor and capital, access to credit facilities, and extension services. The socioeconomic characteristics of respondents are presented in Table 1 below.

Age: The results from Table 1 indicate a significant proportion (46.3%) of respondents were within the age range of 41-50, followed by the age group of 31-40, with a percentage of 26.3. Respondents who are 51 years and above have a percentage of 18.8, with the smallest percentage belonging to the 21-30 years group, at 8.8. It suggests that the majority of respondents were of middle age who are less productive than the youth group (21-30). The findings of this research work are in line with that of Adewumi & Adebayo (2019), which had a majority of the potato farmers within the ages of 41 to 50 years.

Gender: The gender distribution presented in Table 1 shows that the majority of the respondents were males, with a percentage of 72.5, while females accounted for 27.5%. This indicates that men constitute a significant proportion of farmers involved in potato production in the Ankpa local government.

Marital status: The majority (87.5%) of potato farmers were married, with 8.8% being single, 2.5% widowed, and 1.3% separated. Marriage fosters a sense of partnership and collaboration, where spouses offer other. The support is manifested as shared responsibilities, where couples combine their resources, labor, and expertise. This finding is in agreement with that of Ahmad et al. (2014), who reported that the majority of potato farmers were married.

Educational background: The distribution of respondents according to educational level, presented in Table 2, shows that the majority (88.8%) of the respondents had received formal education. Uche et al (2020 had similar findings from their research. while 11.3%) had no formal education, this finding contradicts that of Ahmad and Makama (2014), who found that the majority of the farmers had no formal education but is in agreement with the findings of Sanusi et al. (2020), that majority of the potato farmers had formal education but at different levels. The prevalence of formal education among potato farmers shows a correlation between educational background and involvement in potato farming. Typically, education provides an individual with the capacity to understand and apply technical skills, adopt innovations, and maximize the potential of available technology.

A high proportion (70.0%) of respondents fall within the bracket of 13years and above, followed by respondents who had formal education for 7-12 years, with a percentage of 13.8%, while the smallest percentage (5.0%) corresponds to those with 1-6 years of formal education. The distribution of respondents according to the number of years of formal education in Ankpa local government shows that lot of them (70%) pursued tertiary education, 13.8% obtained their first school leaving certificates and further went to secondary schools but the least group (5.0%) are those who attained formal education within the periods of 1-6 years and at least obtained a first school living certificate.

Religion: Muslims have the highest percentage (51.3%), the Christian religion has a percentage of 48.8, and lastly the traditionalists who have the percentage of 1.3. This means Muslims predominantly dominate the study area and this finding is in contradiction with that of Sanusi and Babatunde (2017) whose work showed that 75.0% of the respondents were Muslims and 25.0% Christians.

Credit facilities: Table 2 indicates that 26.3% of the respondents have access to credit facilities, while a very high proportion (73.8%) do not. Adeyonu et al (2019) have similar results from their findings that more than 50% of the farmers sampled had no access to credit facilities.

Extension services: Table 2 indicates that 33.8% of the respondents have access to extension services and the remaining percentage (66.3%) of the respondents do not have access to extension services. This implies that there would be limited knowledge of technical skills and expertise in innovations that can improve the production and output levels of potatoes.

Source of farm labor: Table 2 indicates that 25.0% of the respondents use their family labor in their farms, 40.0% use hired labor, and 35.0% of respondents employ both family and hired labor in their farms.

Source of farm capital: Table 2 indicates that 3.8% of the respondents are funded or receive government support in their farming activities, a high proportion (76.3%) of the respondents sponsor their activities from personal savings, 5.0% get their capital from banks and the last group is that of respondents (15.0%) who get their farm capital from informal lenders. Adewumi and Adebayo (2019) found out from research that most potato farmers (84%) use their personal savings to fund their farm activities, and because of how small it is, they end up planting on a small scale, which results in reduced output and revenue.

Household size: Table 3 reveals that the majority of the respondents (40.0%) had a household size ranging from 4 to about 6 persons, followed by 31.3% of respondents who reported a household size of 2 to about 4 persons, and 28.8% of the respondents reported having a household size of 6 persons and above. The mean household size is 7.88 persons. This indicates a moderately high household size among potato farmers, which can facilitate a high supply of farm labor. Large household size is helpful as it provides family labor and reduces the cost of hired labor.

Farm experience: The data presented in Table 3 highlights the distribution of farming experience among respondents in the study area. The majority (47.7%) of respondents had potato farming experience of 1 to 5 years. About 26.4% respondents indicated 6 to 10 years of experience. 16.4% of the respondents have 11 to 15 years of experience, and 10.1% of respondents have 16 years or more of farming experience. The calculated mean for years of farming experience is 7.88 years, providing an average representation of the level of experience within the study area. The findings contradict those of Adewumi and Adebayo (2019), who, from their research on profitability and technical efficiency of potato production in Nigeria, discovered that potato farmers in Kwara state have farming experiences of 23 years.

Annual income: The findings from Table 3 show that a proportion (16.3%) of respondents earn between ₦100,000 and ₦500,000 annually, followed by the second group with the percentage 16.3. This group of respondents earns between ₦501,000 and ₦1,000,000 annually, then you have the highest proportion (50.0%) of respondents earning between ₦1,100,000 and ₦5,000,000 annually. Lastly, we have the smallest group (7.6%) who earn from ₦5,100,000 and above annually in the study area.

Major occupation: Table 3 shows that the largest proportion of respondents (58.8%) are primarily civil servants, a significant percentage of 22.5% engage mainly in farming, indicating that after civil service, agriculture is the main occupation for the individuals surveyed. Additionally15.0% are traders and 3.8% are artisans.

Minor occupation: The results show that 85% of the respondents are dependent solely on farming as their minor occupation, 8.8% engage in trading alongside their major occupation, 3.8% of the respondents are involved in civil service as their minor occupation, and finally, the artisans make up 2.5%. This means that no individual of the respondents is involved in just one occupation to take care of themselves and their families. They all supplement their major source of income with farming, civil service, trading activities and some are also artisans.

Farm size: Table 3 reveals that 58.9% of the respondents have farm sizes of 0.1 to 0.5 hectares, 25.1 of % respondents have 0.6 to 1.0 hectares, and finally, 16.4% of the respondents have farm sizes of 1.1 hectares and above. This result corresponds closely with the findings of Ahmad et al. (2014), who reported that most potato farmers have farm sizes ranging from 0.2 to 0.7 hectares.

Awareness of climate change adaptation practices: Table 4 below presents the respondents' level of awareness in the study area regarding climate change adaptation practices. The result reveals that 100.0% of the respondents were aware of climate change. On the awareness of climate change adaptation practices, the following are the outcomes:

i. Crop diversification: 76.3% of the respondents were aware of crop diversification, while 23.8% were not. Crop diversification is a vital climate change adaptation practice that involves growing multiple crops on the same land to reduce dependence on a single crop. This approach helps farmers adapt to climate-related shocks such as droughts, floods, and heat waves.

ii. Drought-resistant crops: 32.5% of the respondents were aware of drought-resistant crops as a means of mitigating the effects of climate change, and 67.5% were not. This shows that about 70% of the farmers were not aware of this adaptation strategy, and this could make them less likely to adopt it. Drought-resistant crops are an essential adaptation strategy for farmers facing climate-related droughts. According to the Intergovernmental Panel on Climate Change (IPCC), droughts are projected to increase in frequency and severity due to climate change (IPCC, 2019). Drought-resistant crops are a vital adaptation strategy for farmers facing climate-related droughts. By adopting these crops, farmers can enhance yields, mitigate crop failures, and improve food security. iii. Changing planting dates: About 72.5% of the respondents were aware of changing planting dates as a climate change adaptation practice, while 27.5% were not. Changing planting dates as a means of mitigating the effects of climate change on production is also an important strategy. Climate change is altering temperature and precipitation patterns, making it challenging for farmers to maintain traditional planting schedules. Changing planting dates is simple yet about 30% of the respondents did not use it. This could be that they are not really aware of climate adaptation strategy. Changing planting dates helps the farmer avoid extreme weather events such as heavy rainfall or heat waves that destroy the seeds planted. It can help farmers capitalize on optimal growing conditions, such as cooler temperatures or evenly distributed rainfall. By planting at the right time, farmers can reduce the risk of crop failure due to weather-related stresses.

iv. Water conservation technique: The result shows that 12.5% of the respondents have knowledge of this practice as a climate change adaptation practice, and 87.5% do not have awareness of water conservation techniques as a climate change adaptation practice. Climate change is altering precipitation patterns, leading to droughts and water scarcity in many regions. Water conservation techniques are essential adaptation strategies to ensure sustainable water management and reduce the impacts of climate change.. v. Soil conservation technique: Climate change is altering precipitation patterns, increasing soil erosion, and reducing soil fertility. Soil conservation techniques are essential adaptation practices to protect soil health, reduce erosion, and promote sustainable agriculture. However, 91.3% of the respondents are not aware of soil conservation techniques as a climate change adaptation practice, and only 8.8% of the respondents in the study area were aware of this adaptation practice.. vi. Weather forecasting: Weather forecasting is the process of predicting the future state of the atmosphere, including temperature, humidity, cloudiness, wind, precipitation, and other weather conditions. Weather forecasting involves using various techniques, tools, and data sources to predict weather patterns and events. In this study, more than half of the respondents (55.0%) are aware of weather forecasting as a climate change adaptation practice, and the remaining 45.0% are not aware of weather forecasting as a climate change adaptation practice. vii. Crop insurance: A very high percentage (97.5%) of the respondents have no knowledge of crop insurance as a climate change adaptation practice. Only 2.5% had knowledge or awareness of crop insurance as a climate change adaptation practice. Crop insurance is a type of insurance that protects farmers and agricultural producers from financial losses due to crop failure, damage, or decline in yield. It provides financial compensation to farmers when their crops are affected by adverse weather conditions, pests, diseases, or other natural disasters.

viii. Method farmers learnt of the adaptation practice: The results showed that respondents who learnt of the climate change adaptation practice through the Government extension services are 15.0%, while 3.8% learnt the practices through non-governmental organizations, 55.0% from fellow farmers, 12.5% through media such as TV, radio, newspaper, and 13.8% from the internet.

Adoption of climate change adaptation practices: Table 5 shows the climate change adaptation practices adopted by the respondents in the study area. Almost all (92.5%) of respondents indicated they adopted some climate change adaptation practices. A few (7.5%) did not adopt any practice. 68.3% indicated that they adopted crop diversification to mitigate climate change effects, while 31.3% did not adopt crop diversification. 28.8% of the respondents indicated they adopted drought-resistant crops as a practice. In comparison while 71.3% indicated they did not adopt them as a result of poor awareness. 52.5% of the respondents adopted changing planting dates as a climate change adaptation practice, but 47.5% did not. 7.5% adopted the water conservation technique, but 92.5% did not adopt the practice. 5.0% of the respondents have adopted soil conservation techniques to mitigate climate change.effects and 95.0% have not adopted the practice. 27.5% of the respondents have adopted weather forecasting to reduce the effects of climate change, while 72.5% of the respondents have not adopted this practice. 2.5% of the respondents have their farms insured, and this helped to reduce outcomes of risk and climate change effects, but 97.5% of them have not adopted this practice, and so any outcome they face from climate change effects may lead to food insecurity in the long run.

Number of adopted practices:The results from Table 5 also shows that of all the respondents, 7.5% indicated that they are yet to adopt a practice from all climate change practices, 20.1% adopted just one of the many practices to climate change effect, 50.0% have adopted two climate change adaptation practices and the last percentage (22.5%) of the respondents have adopted 3 and above climate change adaptation practices.

Effects of adaptation practices on the farmers ' adoption and use of vitamin A potato: The results in Table 6 reveal that several climate change adaptation practices significantly influence farmers' decisions to adopt Vitamin A potatoes in Ankpa Local Government. Among the most influential factors, changing planting dates ($p<0.01$) and soil conservation techniques ($p<0.01$) had positive effects on adoption. This finding aligns with the study by Bryan et al. (2013), which emphasized that adjusting planting schedules helps farmers mitigate climate variability and improve yields. Similarly, soil conservation techniques, including mulching and contour farming, enhanced soil fertility and water retention, creating favourable conditions for Vitamin A potato cultivation. The significance of water conservation techniques ($p<0.01$) also reinforces the importance of sustainable water management in promoting crop adoption under changing climatic conditions (Deressa et al., 2009). Socioeconomic factors also played a critical role in the adoption decision. Educational level ($p<0.01$), access to credit ($p<0.01$), and access to extension services ($p<0.01$) were all positively and significantly associated with the likelihood of adopting Vitamin A potatoes. These findings align with previous research by Feder et al. (1985), which highlighted that higher education levels improve farmers' ability to process agricultural innovations and make informed decisions. Furthermore, access to credit facilitates investment in improved seeds, fertilizers, and irrigation, all of which are necessary for successful adoption. Extension services, as reported by Mwangi & Kariuki (2015), bridge the knowledge gap by providing farmers with technical support and training on climate-smart agriculture, ultimately enhancing adoption rates. The significance of these institutional factors suggests that policies aimed at improving agricultural financing and extension outreach could be instrumental in scaling up Vitamin A potato adoption.

Drought-resistant crops ($p<0.01$) and crop diversification ($p<0.05$) also had a significant positive effect, indicating that farmers who engage in multiple adaptation strategies are more likely to adopt Vitamin A potatoes. This supports the findings of Asfaw et al. (2016), who argued that diversified farming systems reduce risks associated with climate shocks and enhance food security. The positive influence of weather forecasting ($p<0.05$) suggests that access to timely climate information enables farmers to make strategic decisions about when and how to plant, ultimately reducing climate-related risks (Hansen et al., 2011). Overall, these findings emphasize the need for an integrated approach that combines agronomic, financial, and institutional support to enhance the adoption of Vitamin A potatoes as a climate adaptation strategy.

Annual output difference of Adopters and Non-adopters of adaptation practices: The results in Table 7 below reveal a significant difference in annual potato output between farmers who adopted climate change adaptation practices and those who did not. Adopters reported a much higher mean annual output of $\bar{x}=1672.76$, compared to $\bar{x}=116.67$ for non-adopters, suggesting that adaptation strategies play a crucial role in improving productivity. The higher standard deviation among adopters ($\sigma=2052.29$) indicates variability in yields, which differences could influence in the specific practices used, soil conditions, or access to resources (Deressa et al., 2009). This finding is consistent with that of Bryan et al. (2013) and Asfaw et al. (2016), who found that climate adaptation measures such as improved soil and water conservation significantly boost agricultural productivity. The lower and more unstable yields among non-adopters, indicated by a high standard error (SE=74.91), highlight their vulnerability to climate variability. These results emphasized the need to promote climate adaptation strategies through better extension services, financial support, and farmer training programs to enhance productivity and resilience in potato farming (Mwangi & Kariuki, 2015).

The independent samples t-test in Table7 reveals a statistically significant difference in annual potato output between farmers who adopted climate change adaptation practices and those who did not. Levene's test for equality of variances ($p=0.046$) indicates that the assumption of equal variances is violated, necessitating the use of the t-test with unequal variances. The results show a highly significant difference in mean potato output ($t=-5.947$, $p<0.001$), with adopters producing significantly higher yields than non-adopters. The mean difference of -1556.10 kg suggests that adaptation practices contribute substantially to increased productivity. The confidence interval (-2077.88, -1034.31) does not contain zero, reinforcing the robustness of this effect. These findings are consistent with previous research demonstrating that climate-smart practices, such as improved soil and water conservation, crop diversification, and drought-resistant varieties, enhance agricultural yields by mitigating climate risks (Lal, 2015; Kassie et al., 2013).

The large productivity gap between adopters and non-adopters underscores the importance of promoting adaptation strategies to improve food security and resilience among smallholder farmers. Climate variability has been shown to disproportionately affect farmers who lack access to adaptation resources, leading to lower yields and greater economic vulnerability (Mendelsohn, 2014). The significant impact of adaptation practices suggests that increased investment in extension services, credit access, and climate information systems could encourage wider adoption. Di Falco et al. (2011) highlight that farmers with access to climate information and technical support are more likely to implement adaptation measures, ultimately improving agricultural productivity. Given the findings from this study, policies aimed at facilitating farmer access to climate adaptation strategies will enhance agricultural resilience and ensure sustainable food production in the face of climate change.

Conclusion

Adoption and use of bio-fortified Vitamin A potato is dependent on the capacity of smallholder farmers to adapt to climate change agricultural practices. This affects the level of production of Vitamin A potato, especially in a modern-day environment with climate change effects as a deterrent. The farmers were educated, with males of middle age dominating the production. Many had no access to credit and extension services. Many were also aware of the climate change phenomenon, but not all used adaptation practices. The annual output level for those who adopted adaptation practices was higher than that of those who did not use them. The study recommends that the farmers form cooperative societies to enable them to gain access to Bank loans and other economies of scale. Extension agents should also reach out to educate the farmers on the benefits of adopting adaptation practices that can lead to higher farm outputs.

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Table 1: Socioeconomic characteristics of the respondents

Variable	Frequency(n=240)	Percentage	mean
Age (years)			**42.15**
21-30	21	8.8	
31-40	63	26.3	
41-50	111	46.3	
≥51	45	18.8	
Gender			
Male	174	72.5	
Female	66	27.5	
Marital status			
Married	210	87.5	
Single	21	8.8	
Widowed	6	2.5	
Separated	3	1.3	

Field survey, 2024

Table 2: Institutional characteristics of the respondents

Variable	Frequency	Percentage
Religion		
Christian	117	48.8
Muslims	123	51.3
Educational qualification		
No formal education	27	11.3
Formal education	213	88.8
Source of farm labor		
Family labor	60	25.0
Hired labor	96	40.0
Family and hired labor	84	35.0
Credit facilities		
Access to credit facilities	63	26.3
No access to credit facilities	177	73.8
Extension service		
Access to extension service	81	33.8
No access to extension service	159	66.3
Sources of farm capital		
Government	9	3.8
Personal saving	183	76.3
Bank	12	5.0
Informal lenders	36	15.0

Field survey, 2024

Table 3: **Socio-economic characteristics of respondents**

Variable	Frequency	Percentage	mean
Major occupation			
Farming	54	22.5	
Trading	9	3.8	
Civil servant	141	58.8	
Artisan	36	15.0	
Minor Occupation			
Farming	204	85.0	
Trading	21	8.8	
Civil servant	9	3.8	
Artisan	6	2.5	
Household Size (number)			**5**
2-4	75	31.3	
5-6	96	40.0	

>6	69	28.7	
Farming Experience (years)			**7.4**
1- 5	114	47.7	
6-10	63	26.4	
11-15	42	16.4	
=>16	24	10.1	
Farm Size (Ha)			**0.54**
0.1-0.5	141	58.9	
0.6-1.0	60	25.1	
=>1.0	39	16.4	
Annual Income (₦1000)			**2145.75**
100-500	39	16.3	
501-1000	63	26.5	
1100-5000	120	50.0	
>5000	18	7.6	

Field Survey, 2024

Table 4: Level of awareness of climate change adaptation practices

Variable	Percentage Yes	No
Awareness of climate change	100.0	0.0
Awareness of climate change adaptation practices		
Crop diversification	76.3	23.8
Drought-resistant crops	32.5	67.5
Changing planting dates	72.5	27.5
Water conservation techniques	12.5	87.5
Soil conservation techniques	8.8	91.3
Weather forecasting	55.0	45.0
Crop insurance	2.5	97.5
Sources of knowledge of adaptation practices		
Government extension service	15.0	85.0
NGOs	3.8	96.2
Other farmers	55.0	45.0
Media	12.5	87.5
Internet	13.8	82.2

Source; Field survey 2024

Table 5: **Adoption and use of climate change adaptation practices**

Variable	Percentages (Yes)	(No)
Have you adopted adaptation practices?	92.5	7.5
Practices		
Crop diversification	68.3	31.3
Drought-resistant crops	28.8	71.3
Changing planting dates	52.5	47.5
Water conservation techniques	7.5	92.5
Soil conservation techniques	5.0	95.0
Weather forecasting	27.5	72.5
Crop insurance	2.5	97.5
Number of adopted practices		
0	7.5	7.5
1	20.1	27.6
2	50.0	77.6
≥3	22.4	100

Source; Field survey 2024

Table 6: Effects of adaptation practices on the farmer's choice on the adoption of vitamin A potato using Probit regression analysis

Parameter	Estimate	Std. Error	Z	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Age range	0.045	0.018	2.50	0.012	0.010	0.080
Educational level	0.089	0.032	2.78	0.005	0.027	0.151
Crop diversification	0.102	0.040	2.55	0.011	0.024	0.180

Drought-resistant crops	0.137	0.049	2.80	0.005	0.041	0.233
Change in planting dates	0.215	0.056	3.84	0.000	0.105	0.325
Water conservation techniques	0.198	0.072	2.75	0.006	0.057	0.339
Soil conservation techniques	0.174	0.061	2.85	0.004	0.055	0.293
Weather forecasting	0.122	0.048	2.54	0.011	0.027	0.217
Crop insurance	0.108	0.045	2.40	0.016	0.020	0.196
Do you have access to credit	0.147	0.055	2.67	0.008	0.040	0.254
Do you have access to the extension service	0.165	0.058	2.84	0.004	0.051	0.279
Intercept	-1.982	0.278	-7.13	0.000	-2.527	-1.437

Field Survey, 2024

Table 7: Annual output difference for adopters and non-adopters of adaptation practices using Levenes equality for variance and T-test for equality of means

	F-cal	t-tab	Df	Sig-2tail	Conf. int.
Equal variance assumed	5.498	1.845	238	0.046	-3237-125
Equal variance not assumed	-5.947	-1.805	238	0.000	-2077.89-1034

Field Survey, 2024