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Unlocking sustainable agriculture: climate adaptation, opportunity costs, and net revenue for Nigeria cassava farmers

Adewale Isaac Olutumise[1,2] · **Babatunde Peter Ekundayo**[3] · **Akinyemi Gabriel Omonijo**[4] · **Olumide Oyewole Akinrinola**[3] · **Oluyede Adeleke Aturamu**[5] · **Olubukola Omotinuke Ehinmowo**[6] · **Dayo Temitope Oguntuase**[7]

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Abstract

Climate change continues to affect food production and farmers incur additional costs to adopt appropriate adaptation strategies to combat its effects and attain food security. To enhance adaptive and sustainable coping strategies and food security, it is necessary to study the opportunity costs of implementing climate adaptations and how they influence the net revenue of farmers. Therefore, the study empirically investigates adaptation to climate change and the net revenue of cassava farmers in Southwest Nigeria. The primary data used for this study were collected through a well-structured questionnaire for 221 respondents. The analytical methods used were descriptive statistics, paired sample tests, and multiple regression. Analysis revealed that the majority (55%) of the sampled cassava farmers employed planting different varieties and using agrochemicals as their main adaptation strategies. The results revealed that insufficient funding and labour shortage were the main barriers to adaptation in the study area. The results of opportunity cost on net revenue and costs using paired samples test revealed that cassava farmers derived and perceived the utility and the net benefits using adaptation measures than when it is not used. The result of the regression showed that climate variables such as adaptation options, rainfall, and access to climate information are co-joint with socioeconomic and production factors to determine the average net revenue in the area. Therefore, the study suggests that the costs of adaptation resources should be subsidized by the government at affordable prices for the farmers.

Keywords Adaptation · Climate change · Farmers · Perceptions · Opportunity cost · Nigeria

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✉ Adewale Isaac Olutumise, adewale.olutumise@aaua.edu.ng; aolutumise@wsu.ac.za | [1]Department of Agricultural Economics, Adekunle Ajasin University, Akungba-Akoko, P.M.B 001, Ondo State, Nigeria. [2]Department of Economic and Business Sciences, Walter Sisulu University, Mthatha 5117, South Africa. [3]Department of Agricultural and Resource Economics, Federal University of Technology, P.M.B 704, Akure, Ondo State, Nigeria. [4]Department of Water Resources Management and Agrometeorology, Federal University Oye-Ekiti, Oye-Ekiti, Ekiti State, Nigeria. [5]Department of Agricultural Science and Technology, Science and Technology, Bamidele Olumilua University of Education, P.M.B 250, Ikere-Ekiti, Nigeria. [6]School of Agriculture, University of the Virgin Islands, Virgin Islands RRI, Box 10000, Charlotte Amalie, USA. [7]Department of Computer Science, Staffordshire University, Stoke-on-Trent, UK.

1 Introduction

Climate change is widely recognized as a significant threat to global economic development and the sustainability of humanity [1, 2]. Therefore, the increasing variability in climate has emerged as one of the most critical environmental challenges mankind faces. Shreds of evidence also abound that link climate change to a range of ecological problems in Nigeria [3–5]. For example, Southwest states in Nigeria have experienced severe floods since 2012, resulting in loss of life, displacement, and damage to farmlands. Erosions caused by excessive rainfall remain a threat to crops and farmlands [6]. Variability in Nigerian rainfall and temperature, as affirmed by [2, 7], directly has consequences on agricultural production. For instance, higher temperatures reduce crop yields and encourage weeds and pests' proliferation, while changes in precipitation patterns increase the risk of short-term crop failure and long-run production declines. Consequently, climate variability poses a serious challenge to food production [8, 9].

Agriculture in Nigeria, like in many African countries, relies heavily on weather-sensitive production systems, making it highly vulnerable to climate change [10]. This vulnerability is evident in the devastating flooding in the Southwest and prolonged droughts in the Northern regions. In response to climate change threats, Nigerian farmers are adopting various adaptation strategies to mitigate these consequences [6, 11–13].

Nigeria stands as the world's foremost producer of cassava, annually yielding over 59 million tonnes of fresh cassava roots [14]. The significant boost in production witnessed over the past 26 years (1994–2019) can largely be attributed to the development of enhanced cassava varieties and the expansion of cultivation areas dedicated to cassava [14, 15]. However, the average cassava tuber yield is still below its potential productivity [2, 15]. Also, cassava farmers, like other crop farmers, are implementing adaptation methods such as adopting new crop varieties, livestock diversification, irrigation, crop diversification, mixed farming systems, and changing planting dates [2, 16]. However, the impact of these measures on food availability remains limited, primarily due to the associated costs, especially for smallholder farmers with limited resources [6, 17, 18]. Had this not been so, one wonders why adaptation, one of the policy options for reducing the negative impact of climate change has not played its role as expected in developing countries.

Moreover, rapid population growth and the need to address food supply challenges further compound the climate change issue [2]. Climate change, attributed to human activities, continues to affect food production [12]. Therefore, these non-stop climate change effects demand corresponding non-stop research on climate change and food crops. Given the importance of cassava in Nigeria, where it plays a significant role in poverty alleviation, job creation, and revenue generation, understanding its vulnerability to climate change is crucial [19, 20]. This research aims to provide insights into the adaptation of cassava farmers to climate change, which can inform policies on food security, rural–urban migration, responses to climate variations, and holistic agricultural development.

Numerous studies have explored the impact of climate change on agriculture, particularly cultivated crops in Nigeria. These impacts stem from variations in key climatic variables, including rainfall, temperature, sunshine intensity, relative humidity, atmospheric pressure, cloud cover, snow, dew, frost, and wind [6, 13, 21, 22]. However, previous research, such as [23–27] employ logistic and ordinary least square (OLS) regression models to address factors influencing farmers' decisions to adopt climate change adaptation measures; perceptions of the farmers on climate change effects, and the adaptation strategies employed by the farmers. None of these studies addresses the cost–benefit analysis of adaptation strategies. Therefore, it has been observed that little or no effort has been geared toward the estimation of the cost incurred as a result of adaptation strategies adopted by the farmers, particularly the cassava farmers. Climate change is area-specific with diverse features in each geographical location. Therefore, comparing different agroecological zones in the same region is one of the novelties of this present study. The introduction of the concept of opportunity cost (OC) in addressing the cost–benefit analysis of adapting to climate change effects with a focus on cassava farmers is also a novelty. Findings from this research are expected to aid the understanding of farmers' responses and adaptation strategies to climatic variation and help in designing appropriate policy frameworks that will enhance adaptive and sustainable coping strategies as well as food security. In filling this gap, the study empirically assesses the farmers' awareness of climate change, examines the farmers' perceptions of climate change, identifies the primary adaptation strategies employed by farmers, describes the main obstacles to climate change adaptation in the region, estimates the opportunity cost associated with adopting adaptation strategies for inputs and output outcomes, and determines the impact of climate change adaptation on the net revenue of farmers.

2 Materials and methods

This study was conducted in Southwest, Nigeria comprising Ogun, Osun, Ondo, Oyo, Lagos, and Ekiti States (Fig. 1). The study area is agrarian and agriculture remains the hub of the economy employing over 70 percent of the population. The region's population resides on 76,852 square kilometers of land, with the Kwara and Kogi States to the north and east, the Republic of Benin to the west, and the Atlantic Ocean to the south. It encompasses longitudes 2°31′ and 6°00′ East and latitudes 6°21′ and 8°37′ North [6, 28]. The area comprises three main agro-ecological zones: the coastal swamp, the middle tropical rainforest, and the northern guinea savannah. The region has 842,499 hectares of forested area, with 85 forest reserves. The region has a tropical climate with two distinct seasons, 21 °C to 34 °C temperatures, and 1500–3000 mm of annual rainfall [12]. The Northeast trade wind from the Sahara affects the dry season, while the Southwest monsoon wind from the Atlantic causes the wet season. Along the coast are freshwater swamps and mangrove forests; lowland forests stretch to Ogun and portions of Ondo state; while in the north, secondary forests give way to southern Savannah.

Primary data used for this study were collected through direct personal interview schedules and Focus Group Discussion sessions (FGDs) with the aid of a structured questionnaire. Informed consent was obtained from all individual participants included in the study. A multi-stage sampling procedure was used for the selection of the respondents. Stage one involved the purposive selection of three (3) States (Ondo, Ogun, and Oyo) in Southwest Nigeria, being the leading cassava-producing States in the area. The second stage involved a random selection of three (3) Local Government Areas (LGAs) from each State. In the third stage, five (5) communities were randomly selected from each LGA. Finally, stage four involved a random selection of five (5) registered cassava farmers from each community, therefore making a total of 225 respondents but 221 respondents' data were valid and employed for this study as also presented in Table 1. Opportunity cost approach, Ordinary Least Squares (OLS), and descriptive statistics such as percentages, mean, standard deviation, and tables with a Likert Rating Scale (LRS) were used for the analysis of this study.

2.1 The concept of opportunity cost

Opportunity Cost exists when there are at least two courses of action and the decision maker can select either course. The value of the rejected choice is sacrificed or given up by the decision maker and this sacrificed value is

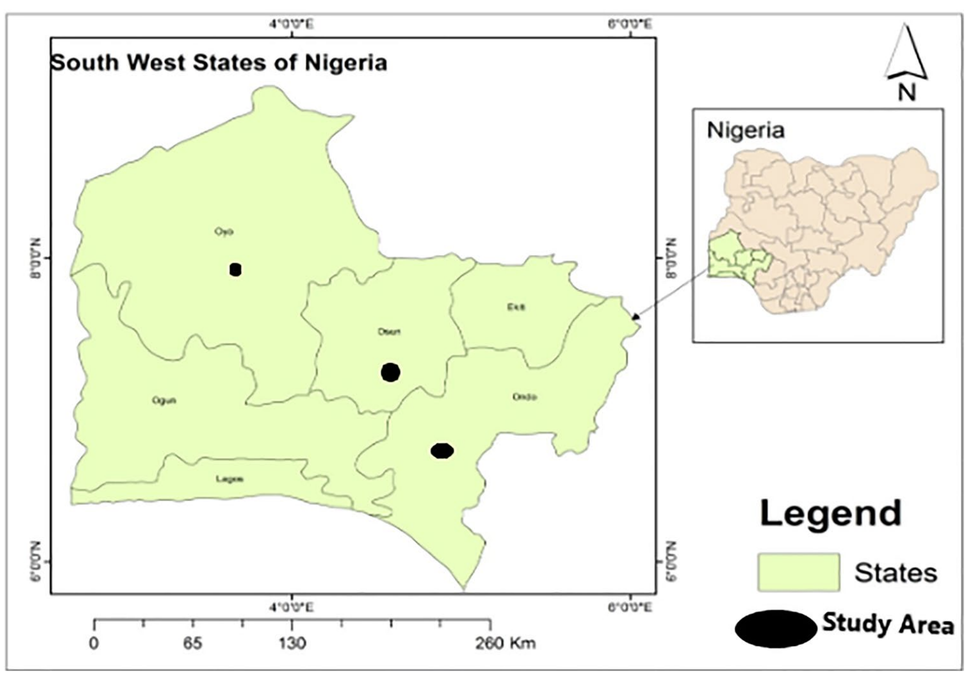

Fig. 1 Map of the study area—Southwest Nigeria

Table 1 Summary of the Multistage Sampling

State	LGA	Community	Sampled
Ondo	Akure North	Iju, Itaogbolu, Ayede-Ogbese, Igoba, Obaile	72
	Owo	Owo, Emure-Ile, Uso, Isuada, Tapere	
	Odigbo	Ore, Araromi, Oniparaga, Alawaye, Abojupa	
Ogun	Odeda	Alayin, Lemo, Segile, Erinle, Ojebiyi	74
	Ijebu North	Balufon, Elewedu, Erilamo, Feoseje, Togedengbe	
	Abeokuta North	Akinniyi, Aragba, Baale, Odango, Orunto	
Oyo	Ibarapa East	Otayanrin/Eruwa, Gbohungbohun/Eruwa, Lanlate, Eruwa, Elere/Eruwa	75
	Iseyin	Olose, Owonitola, OdoOgba, Ogundipe, Oguntunji	
	Saki West	Ataye, Asabari, Oge, Tenleke, Ataye	
Total	9	45	221

the (opportunity) cost of the choice. A fundamental principle of economics is that every choice has an opportunity cost. OC focuses on the quantitative evaluation of the adaptation strategy's impacts on cassava farmers' revenue. This approach identifies the adaptation strategies employed in the households and for each adaptation strategy, the total costs incurred and benefits accrued with and without the strategy were compared using the Paired Samples Test.

A paired samples test of the difference between the two means was used to determine whether the mean differences in the net revenue and costs as a proxy to the opportunity cost of adopting an adaptation measure are significant or not. Following [29, 30], the Eqs. 1 and 2 present the mathematical expression for the test given as:

$$T = \frac{x_1 - x_2}{\sqrt[e]{1/n_1 + 1/n_2}} \tag{1}$$

$$\sigma = \sqrt{\frac{n_1 {s_1}^2 + n_2 {s_2}^2}{n_1 + n_2 - 2}} \tag{2}$$

Where: T = the Paired Samples test distribution.

Degree of Freedom (df) = $n_1 + n_2 - 2$

x_1 = mean (costs and revenue) without the adoption of adaptation strategies.

x_2 = mean (costs and revenue) with the adopting adaptation strategies.

σ = Standard deviation of x_1 and x_2

n_1 and n_2 = number of observations.

s_1 = standard deviation without the adoption of adaptation strategies.

s_2 = standard deviation with the adoption of adaptation strategies.

2.2 The Cobb–Douglas production function

To assess how socioeconomic, production, and climate factors influence cassava farmers' net revenue in the study area, we employed a Cobb–Douglas production function. In the existing literature, two main models have been used to estimate the economic impact of climate change on agricultural productivity [21, 31–33]. The first approach is the general equilibrium (economy-wide) model, which examines the economy as a system of interdependent sectors. The second approach is the partial equilibrium model, which focuses on the part of the economy. Following the methodology of [21, 32], we employed the partial equilibrium approach, which encompasses agroecological zoning (AEZ), production functions, and the Ricardian framework. The Ricardian model uses a cross-sectional approach to estimate agricultural production based on agroclimatic factors and the value of farmland or net revenue [32–34]. One of the advantages of this model is its capacity to incorporate cassava farmers' adaptation responses to local climates [33, 35, 36]. Additionally, it is cost-effective because the data on climate variables, production, and socioeconomic factors can be easily obtained [21]. Due to the limited data availability and the nature of farmers in the study area, we chose the production function approach while using net revenue as the dependent variable,

Table 2 Awareness of climate change by the respondents

	State of the respondents						Pool sample	
	Ondo state		Ogun state		Oyo state			
	Freq	Percent	Freq	Percent	Freq	Percent	Freq	Percent
Awareness								
No	5	6.9	11	14.9	8	10.7	24	10.9
Yes	67	93.1	63	85.1	67	89.3	197	89.1
Total	72	100.0	74	100.0	75	100.0	221	100.0
Level of awareness								
Low	8	11.9	7	11.2	13	19.4	28	14.2
Moderate	45	67.2	28	44.4	33	49.3	106	53.8
High	14	20.9	28	44.4	21	31.3	63	32.0
Total	67	100.0	63	100.0	67	100.0	197	100.0

aligning with the Ricardian model, a common approach in the literature [37]. Net revenue reflects the land's net productivity, similar to the value of land [32, 33]. The profit function's theoretical foundation is also a variant of the Ricardian model [32, 38]. This variant assumes that climate changes prompt farmers to adapt to the most profitable alternatives by altering their choice of crops, seed varieties, and technologies, among other factors, under the assumption of efficient markets where land rents reflect the land's optimal use and anticipated profitability [32–34]. In well-functioning markets, net revenue should be equivalent to farmland value. As highlighted by [32], another advantage of using net revenue lies in the possibility that land values may encompass speculative components unrelated to climate. Farmers aiming to maximize profit should align their crop selection, input utilization, and other factors with anticipated climate conditions [34]. Moreover, employing net revenue eliminates the need for assumptions about the efficiency of land markets. Additionally, by directly incorporating climate variation variables into the regression model, specific assumptions about farmers' risk aversion are unnecessary, as the direct relationship of this variation to net revenue reveals producers' reactions to climate risk [34]. Accordingly, the net revenue of the cassava farmers is modelled as a function of net productivity and costs of cassava farming per hectare, as shown in Eq. (3).

$$the\ theY = \int \sum P_y Q - \sum P_X X \tag{3}$$

Where; Y is the net revenue in naira (N) per hectare, P_y is the price of cassava output per hectare, Q is the cassava output per hectare, X is the vector of inputs, and P_x is the vector of input prices.

The Cobb–Douglas function is based on modeling the non-linear relationship between net revenue and climate variables including the socioeconomic and production factors as also carried out in studies [31, 33, 37]. The relationship is represented in the Eq. (4) as:

$$lnY = \beta_o + \gamma_i lnSF_i + \delta_i lnPF_i + \theta_i lnCF_i + \varepsilon_i \tag{4}$$

Where; SF_i represents the vector of the socioeconomic factors such as age (years), household size (numbers), education (1 = educated and 0, otherwise), experience (years), access to credit (1 = yes and 0, otherwise), and locations (Oyo, Ogun, Ondo).

PF_i represents the vector of production factors such as prices of cassava per hectare (N), farm size (hectares), labour cost (N), planting materials (N), depreciation cost on fixed inputs (N), and agrochemical costs (N).

CF_i represents the vector of climate factors such as adopted adaptation strategies (numbers), perceived rainfall (1 = increased and 0, otherwise), perceived temperature (1 = increased and 0, otherwise), and access to climate information (1 = yes and 0, otherwise).

The β_o denotes the constant coefficients, γ_i, δ_i, θ_i are the vectors of parameters to be estimated, *ln* is the natural logarithms, and ε_i is the error terms.

3 Results and discussion

3.1 Awareness of perceived effects of climate change on cassava production

The results presented in Table 2 revealed that approximately 89% of the respondents were aware of the repercussions of climate change on cassava production over the years, whereas 11% of them asserted that they were not aware. Additionally, this awareness varied across the States, with 93%, 85%, and 89% of the respondents from Ondo, Ogun, and Oyo States respectively, indicating their awareness of climate change in their respective locations. Again, the study delved into the depth of understanding among those respondents who claimed awareness of climate change and its impact on cassava production. The results indicated that the majority (54%) of respondents possessed a moderate level of awareness, while approximately 32% demonstrated a high level of awareness. Conversely, 14% of the sampled respondents exhibited a low level of awareness in the area. In Ondo State, the breakdown showed that about 12%, 67%, and 21% of respondents claimed to have low, moderate, and high levels of awareness regarding the effects of climate change on cassava production. Similarly, in Ogun State, nearly 11%, 44%, and 44% of the respondents affirmed low, moderate, and high levels of awareness concerning climate change's influence on cassava production. Meanwhile, in Oyo State, approximately 19%, 49%, and 31% of the respondents attested to low, moderate, and high levels of awareness, respectively, regarding climate change's impact on cassava production in the area. Although the results indicated varying levels of awareness among the respondents, a noteworthy increase in awareness was observed. Nevertheless, there remains a need for further efforts to educate them comprehensively about the consequences of climate change on cassava production. Such awareness can guide respondents in adopting necessary adaptation measures to counteract the adverse effects of climate change on cassava production. It can also encourage them to explore mitigation strategies aimed at restoring environmental stability, as previously discussed by [39, 40].

3.2 Perceptions of respondents on selected climatic variables (Temperature and Rainfall)

We gathered the perceptions of the respondents concerning changes in temperature and rainfall patterns over the years. Table 3 illustrates the perceptions of the sampled respondents about these selected climatic variables. The results of our analysis regarding cassava farmers' perceptions of temperature indicated that the majority (72%) of the respondents believed that temperature had been rising over the years in the study area. Approximately 20% of them held the view that temperature had been decreasing, while around 4% perceived no change in temperature over the years. An additional 3% reported that they did not know whether temperature had changed or remained the same over the years. Examining results across the states, it was evident that nearly 57%, 78%, and 80% of respondents in Ondo, Ogun, and Oyo States, respectively, perceived temperature increases as the prevailing trend in their areas.

Regarding rainfall, the results revealed that many (56%) of the respondents perceived a reduction in rainfall over the years, while 36% believed that rainfall had been on the rise. About 3% perceived no change in rainfall patterns, while 5% indicated that they did not know whether rainfall had changed or not. Furthermore, when examining the

Table 3 Distribution of respondents by perceptions of temperature and rainfall

Perceptions	Temperature								Rainfall							
	State of the respondents						Pool Sample		State of the respondents							
	Ondo State		Ogun State		Oyo State				Ondo State		Ogun State		Oyo State		Pool sample	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Do not know	5	6.9	2	2.7	–	–	7	3.1	7	9.7	2	2.7	3	4.0	12	5.4
Decreasing	24	33.3	10	13.5	11	14.7	45	20.4	45	62.5	51	68.9	27	36.0	123	55.7
Stay the Same	2	2.9	3	4.1	4	5.3	9	4.1	–	–	3	4.1	4	5.3	7	3.2
Increasing	41	56.9	59	79.7	60	80.0	160	72.4	20	27.8	18	24.3	41	54.7	79	35.7
Total	72	100.0	74	100.0	75	100.0	221	100.0	72	100.0	74	100.0	75	100.0	221	100.0

Table 4 Major adaptation measures employed by cassava farmers in the study area

SN	Adaptation strategies	State of the Respondents						Pool sample	
		Ondo State		Ogun State		Oyo State			
		Freq	Percent	Freq	Percent	Freq	Percent	Freq	Percent
1	Planting Different Varieties (PDV)	26	36.1	28	37.8	45	60.0	99	44.8
2	Practicing Crop Diversification (PCD)	7	9.7	26	35.1	1	1.3	34	15.4
3	Different Planting Dates (DPD)	21	29.2	27	36.5	22	29.3	70	31.7
4	Mixed Cropping (MC)	25	34.7	33	44.6	53	70.7	111	50.2
5	Soil Conservation Techniques (SCT)	21	29.2	30	40.5	39	52.0	90	40.7
6	Use Of Agrochemicals (UAC)	28	38.9	30	40.5	54	72.0	112	50.7
7	Move To Different Site (MDS)	14	19.4	25	33.8	6	8.0	45	20.4

Table 5 Main hindrances to adaptation strategies in the study area

SN	Hindrances/barriers to adaptation	State of the respondents						Pool sample	
		Ondo State		Ogun State		Oyo State			
		Freq	Percent	Freq	Percent	Freq	Percent	Freq	Percent
1	Inadequate information	34	47.2	20	27.0	12	16.0	66	29.9
2	Inadequate funding	48	66.7	34	45.9	58	77.3	140	63.3
3	Shortage of labour	37	51.4	35	47.3	51	68.0	123	55.7
4	Shortage of land	36	50.0	11	14.9	22	29.3	69	31.2
5	Poor potential for irrigation	32	44.4	21	28.4	-	-	53	24.0
6	Inadequate technology know-how	28	38.9	14	18.9	–	–	42	19.0
7	Lack of good and resistant planting materials	31	43.1	27	36.5	3	4.0	61	27.6
8	Rapid infestation of pests and diseases	32	44.4	25	33.8	–	–	57	25.8
9	Non-availability of agrochemicals	32	44.4	10	13.5	–	–	42	19.0
10	Poor road/transportation problem	38	52.8	33	44.6	26	34.7	97	43.9

perceptions across states, approximately 63% and 69% of respondents in Ondo and Ogun States, respectively, perceived declining rainfall trends, which constituted the majority opinion in the study area. In Oyo State, the majority (55%) of respondents perceived an increase in rainfall over the years, differing from the responses in the other states.

3.3 Major adaptation measures commonly employed by cassava farmers in the area

As illustrated in Table 4, the majority of cassava farmers (51%) in the study area identified the use of agrochemicals as their preferred adaptation strategy. The preference for agrochemicals could be attributed to their availability and effectiveness when applied by farmers. Additionally, it has contributed to a reduction in the need to change farmland.

Around 50% of the respondents adopted mixed cropping as an adaptation strategy. Farmers indicated that mixed cropping serves as a supplementary income source when other crops are planted alongside cassava. About 45% of cassava farmers chose to plant different cassava varieties as an adaptation measure, while 32% employed varied planting dates to mitigate uncertainty in the area. Approximately 41%, 20%, and 15% of the sampled respondents employed soil management techniques, relocating to different sites, and practicing crop diversification, respectively, as adaptation strategies in the study area. These adaptation measures align with findings in existing literature [6, 13, 41, 42].

In Ondo State, it was observed that the majority (38.9%) of respondents employed mixed cropping as their preferred adaptation strategy, followed by 36.1% who used different cassava varieties and 34.7% who utilized mixed cropping as their adaptation method in the area. In Ogun State, nearly 44.6% of respondents predominantly relied on mixed cropping as their chosen means of adaptation, while 40.5% mentioned employing soil management techniques and the use of agrochemicals. In Oyo State, 72.0% of respondents favoured the use of agrochemicals as their primary adaptation measure, followed by 70.7% who adopted mixed cropping and 60.0% who chose to plant different cassava varieties as their adaptation strategies in the area. According to the findings of [44–46], farmers' choices of adaptation measures may be primarily motivated by profit rather than climate change-driven. However, this study, consistent with the assertions of [21, 43], operates under the assumption that farmers' actions are influenced by climate factors.

3.4 Main barriers to adaptation strategies in the study area

The analysis of the main barriers to adaptation to climate change among cassava farmers in the study area is presented in Table 5. This analysis revealed that farmers identified ten major constraints, some of which they considered as hindrances to adaptation, while others were perceived as resulting from the inadequacy or scarcity of resources in the area. These constraints encompassed inadequate funds, insufficient information, labour shortages, land scarcity, limited technological knowledge, as well as other challenges like poor road networks, lack of quality and resistant planting materials, rapid infestations of pests and diseases, and the unavailability of agrochemicals. Many of these constraints are intertwined with issues of poverty and the negligence of the agricultural sector by the government [47].

The results demonstrated that 63.3% of the sampled cassava farmers identified inadequate funds as their main obstacle to adopting adaptation strategies in the area. A similar trend was observed across the states, with 66.7%, 45.9%, and 77.3% of respondents from Ondo, Ogun, and Oyo, respectively, expressing concerns about inadequate funds. This common complaint could be attributed to the limitations and financial constraints farmers face when attempting to acquire the necessary resources, especially inputs and technologies required for effective adaptation.

Approximately 55.7% of respondents affirmed labour shortages as their main barrier to adapting to climate change. This concern was mirrored across the states, with 51.4%, 47.3%, and 68.0% of respondents from Ondo, Ogun, and Oyo, respectively, acknowledging labour shortages as their main challenge in adopting adaptation measures. Given that adaptation to climate change often incurs costs [6, 21, 48], the need for intensive labour may contribute to these expenses. Consequently, if farmers lack sufficient family labour or the financial means to hire labour, their capacity to adapt will be limited. Furthermore, in this study area, farmers are increasingly losing family labour to other sectors, especially education. As a result, youths are becoming less engaged in farming activities, perceiving it as a less desirable profession [39, 47].

In addition, nearly 43.9% of respondents reported that poor road networks and transportation problems were their main constraints to adopting adaptation strategies. This issue was also evident in the states, with 52.5%, 44.6%, and 34.7% of respondents from Ondo, Ogun, and Oyo States, respectively, facing similar challenges. The majority of roads leading to their farms were reported to be in poor condition, making them impassable. While farmers in the study area are neither extremely impoverished nor wealthy, they often cannot afford to invest in road construction and acquire new technologies required for climate change adaptation.

The non-availability of agrochemicals was cited as a constraint by 49.0% of the respondents, with 44.4% and 13.5% of respondents from Ondo and Ogun States, respectively, also identifying this problem. About 31.2% of the sampled cassava farmers claimed that land scarcity was the primary reason behind their inability to adopt adaptation strategies. The same problem was shared by 50.0%, 14.9%, and 29.3% of the respondents from Ondo, Ogun, and Oyo States, respectively. The shortage of land in the study area was attributed to communal land tenure systems and the allocation of land for other purposes such as infrastructure, residential development, and institutions. These factors forced farmers to cultivate on smaller plots of land, restricting their ability to engage in adaptation practices that compete for agricultural land.

Inadequate climate information was reported by 29.9% of the respondents, with 47.2%, 27.0%, and 16.0% of the respondents from Ondo, Ogun, and Oyo States, respectively, sharing the same view. The scarcity of information on suitable adaptation options may be attributed to the lack of research on climate change and adaptation options, as well as inefficient meteorological stations in the country. Furthermore, the information on climate change often does not reach farmers, who are key stakeholders in this context, due to the inaccessibility and unaffordability of the means used to disseminate climate information.

Rapid infestations of pests and diseases accounted for 25.8% of the respondents, with 44.4% and 33.8% of respondents from Ondo and Ogun States, respectively, reporting similar problems. Other constraints mentioned by respondents included the poor potential for irrigation (24.0%), the lack of quality and resistant planting materials (27.6%), and inadequate technological know-how (19.0%). Moreover, the technological knowledge levels of these farmers are notably lower when compared to developed countries. Insufficient technological know-how was identified as one of the gaps in local knowledge for adapting to climate change.

3.5 Effect of opportunity cost (OC) of adaptation strategies on net revenue of the farmers

The study evaluated the costs and benefits associated with the adoption of adaptation measures in the area. Table 6 presented the findings, revealing that cassava farmers incurred an additional labour cost of N2,386.38 due to the adoption of any of the identified adaptation measures in this study. Importantly, it was observed that this difference was not statistically significant ($P > 0.05$) according to paired sample tests. Similarly, despite the insignificance of the difference in fertilizer costs incurred by the farmers, they still experienced additional expenses of N5,085.06 as a result of adapting to climate change.

In the case of expanding the cultivated area, a statistically significant difference ($P < 0.05$) was observed, resulting in additional costs of N10,550.00. An additional cost of N2,648.49 was recorded for pest management, with no statistically significant difference. However, concerning planting materials, a statistically significant difference ($P < 0.05$) in additional costs was observed with and without adopting adaptation measures, amounting to N13,217.87.

Furthermore, the study presented the benefits derived from the adoption of climate adaptation strategies in the Table. It was noted that on average, cassava stem cuttings yielded an additional income of about N18,242.46 per hectare (calculated as 35,937.64 divided by 1.97) as a result of implementing adaptation strategies in the area. Additionally, the sales of cassava tubers generated an extra revenue of N255,395.37 per hectare (calculated as 503,128.88 divided by 1.97) when adaptation strategies were employed. The mean difference between the revenue values obtained without adaptation strategies and with adaptation strategies showed statistical significance at the 1% level. This implies that cassava farmers increased their earnings by an additional N237,637.83 per hectare (OC) when utilizing adaptation strategies in the area. These results were expected since the adoption of agricultural technologies is rooted in farmers' pursuit of utility and profit maximization [49]. According to [39, 46, 47], farmers embrace new technologies when they perceive significantly greater utility or profit in comparison to traditional methods. Consequently, households with higher incomes and more substantial assets are better positioned to embrace new farming technologies, which serves as a proxy for adaptation strategies in the case of cassava farmers in the study area (Additional file 1).

3.6 The co-joint effect of climate change on the net revenue of cassava farmers

The variable estimates were subjected to analysis using a double-log form of a multiple regression model, as presented in Table 7. The data were run using several variables under the broad socioeconomic, production, and climatic factors, but only sixteen variables were finally adopted for the model. Other variables were removed due to multicollinearity problems and insignificance. The R-squared value of 0.762 indicated that approximately 76.2% of the variations in the

Table 6 Distribution of respondents by costs and benefits of adaptation strategies

Items	Without adaptation	With adaptation	Difference	t-value	Sig
Average costs incurred					
Labour (₦)	38,120.0	40,506.38	2,386.38	0.348	0.201
Fertilizer (₦)	11,947.37	17,032.43	5,085.06	1.487	0.103
Area expansion under cultivation (₦)	5,583.33	16,133.33	10,550.00	2.655**	0.001
Pest management (₦)	3,533.33	6,181.82	2,648.49	1.521	0.101
Planting materials (₦)	13,280.00	26,497.87	13,217.87	5.619***	0.000
Average benefit accrued					
Sales from stem cuttings (₦)	21,633.33	57,570.97	35,937.64	8.982***	0.000
Sales from cassava tubers (₦)	303,392.86	806,521.74	503,128.88	32.631***	0.000
Total revenue (₦)/ha	164,987.91	438,625.74	273,637.83		

1 US dollar is equivalent to 638.7 naira ($1 = (₦)638.7)

* denotes significant at 10% level

** denaote significant at 5% level

*** denote significant at 1% level

Table 7 Results for the effect of climate change on the farm net revenue

Variable	Coefficient	Std. Err	t-ratio	p-value	Mean	SD
Socioeconomic factors						
Age	0.231*	0.138	1.67	0.096	48.35	41.01
Household size	−0.105	0.085	−1.23		7.00	5.02
Education	0.011	0.524	0.02	0.901	0.68	0.51
Experience	0.006**	0.002	2.57	0.010	41.24	23.67
Access to credit	0.791***	0.183	4.32	0.000	0.43	0.52
location						
Oyo_state	−0.011**	0.004	−2.48	0.013	0.73	0.89
Ondo_state	0.032*	0.017	1.88	0.059	0.75	0.81
Production factors						
Price of cassava/ha	0.099**	0.044	2.24	0.025	69,514.07	81,332.02
Labour cost	5.32e−05	6.54e−05	0.81	0.703	40,506.38	21,921.01
Fixed items	−0.001	0.048	−0.02	0.421	23,011.09	34,344.10
Agrochemicals	−0.003	0.007	−0.43	0.612	9,831.99	12,092.13
Planting material	0.237***	0.092	2.58	0.001	26,497.87	15,001.91
Farm size	0.182**	0.074	2.45	0.014	1.98	4.67
Climate factors						
Adaptation strategies	0.504**	0.241	2.09	0.036	7.81	3.44
Perceived rainfall	−0.392**	0.197	−1.99	0.046	0.27	0.11
Perceived temperature	0.059	0.089	0.66	0.346	0.89	0.23
Access to climate information	0.582***	0.092	6.34	0.000	0.67	0.45
Constant	7.312	1.989	3.69	0.000		
R-square	0.76					
Adj. R-square	0.74					
F-value	26.42***					

* denotes significant at 10% level

** denote significant at 5% level

*** denote significant at 1% level

average net revenue of farmers could be explained by the selected explanatory variables. This indicates a strong goodness of fit for the model. The F-statistic value, which was 26.42, was significant at the 1% level, indicating that all the independent variables collectively influence the model. Additionally, it was observed that ten variables achieved statistical significance in explaining cassava farmers' net revenue in the area.

3.7 Socioeconomic factors (SF)

Among the estimated variables in this category, age, access to credit, experience, and Ondo location were positive and statistically significant, while the Oyo location had a negative coefficient that was also statistically significant in explaining farmers' net revenue. The coefficient for age was positive and statistically significant at a 10% level. This implies that a 1% increase in respondents' age would lead to a 0.23% increase in net revenue. This could be attributed to the economic and productive capacity of farmers, allowing them to contribute to climate change adaptation. This finding aligns with [50] but contrasts with [51], who found an inverse relationship between household head age and farmers' productivity. The coefficient for experience was positive at a 5% statistical significance level, indicating that an increase in years of experience among cassava farmers by 1% would result in approximately a 0.01% increase in net revenue. This suggests that experienced cassava farmers possess expertise in farm management and risk management when faced with climate change fluctuations, contributing to increased income. This result is supported by [48]. The coefficient for access to credit was positive at a 1% significance level, implying that access to credit facilities would lead to an approximately 0.08% increase in net revenue compared to those without access, *ceteris paribus*. This finding concurs with [39], who reported a positive and significant relationship between credit facilities and crop output among rural farmers in Ondo State, Nigeria. The location variable also played a significant role in climate change and net revenue. The Oyo state location had a negative coefficient that was statistically significant at a 5% level, suggesting that cassava farmers in Oyo state are likely to experience a 0.01% decrease in net revenue compared to those in Ogun state. Conversely, the Ondo state location had a positive coefficient that was significant at a 10% level, indicating that cassava farmers in Ondo state may accrue a 0.03% increase in net revenue compared to their counterparts in Ogun state. This underscores the significance of geographical locations in addressing climate change, as emphasized by previous studies such as [12, 48, 52].

3.8 Production factors (PF)

Among the variables in this category, the prices of cassava output per hectare, planting materials, and farm size were statistically significant in explaining cassava farmers' net revenue. The coefficient for cassava prices was positive and significant at a 5% level, indicating that a 1% increase in cassava price would lead to approximately a 0.10% increase in net revenue. This is expected, as higher prices motivate farmers to be more committed and efficient in cassava cultivation, as reported by [20]. Furthermore, the positive and significant coefficient for planting materials suggests that a 1% increase in their cost would result in a 0.24% increase in net revenue, *ceteris paribus*. At a 5% significance level, farm size and net revenue exhibited a positive relationship, implying that a 1% increase in farm size would lead to a 0.18% rise in farmers' net revenue. This may be attributed to larger farms experiencing climate change effects more frequently and adopting necessary adaptations to maximize yield. This aligns with the findings of [53, 54].

3.9 Climate factors (CF)

In this category, variables including the number of adopted adaptation strategies, perceived changes in rainfall, and access to climate information were statistically significant in explaining the average net revenue of cassava farmers. A positive and significant relationship was found between the number of adopted adaptation strategies and net revenue, suggesting that a 1% increase in the number of adaptation strategies adopted would lead to a 0.50% increase in net revenue. This result is consistent with the findings of [33, 48], who reported a positive association between net revenue and the adoption of climate adaptations. Furthermore, a statistically significant negative relationship was observed between perceived increases in rainfall and net revenue, indicating that farmers who perceived a decrease in rainfall would result in a 0.39% decrease in cassava farmers' net revenue compared with those who perceived otherwise in the study area. This observation is corroborated by the findings of [55]. Lastly, access to climate change information was positive and strongly significant in addressing average net revenue at a 1% level. This indicates that access to climate change information will lead to about a 058% gain in the net revenue compared with those cassava farmers without access. Several studies [9, 12, 39, 48] have reported that climate information significantly influences farmers' decisions on climate adaptation strategies that would significantly increase farmers' productivity vis-à-vis net revenue.

4 Conclusion and recommendations

The study concluded that there is a moderate level of awareness and perceptions of climate change as it affects cassava production in the area. It was also concluded that cassava farmers perceived that temperature is increasing over the years while the amount of rainfall was perceived to be decreasing over the years. It was observed that cassava farmers acknowledge that climate change has been affecting cassava production, leading them to adopt various adaptation measures to mitigate its effects. The main adaptation strategies employed by cassava farmers include planting different varieties, practicing crop diversification, mixed cropping, implementing soil conservation techniques, using agrochemicals, and relocating to different sites. Also, the adoption of these adaptation strategies comes with an opportunity cost, which should be considered in decision-making. Furthermore, socio-economic factors such as age, experience, credit, and location play significant roles in addressing average net revenue. Again, the production factors such as the price of cassava, planting materials, and farm size are very germane in boosting the net revenue. Also, climatic factors, particularly the number of adaptation strategies adopted, perceived changes in rainfall, and access to climate change information, significantly interact with production and socioeconomic factors to influence average revenue. It is therefore concluded that cassava farmers derived and perceived utility and the net benefit from using adaptation measures than when it is not adopted. Based on these findings, intensify efforts to organize and strengthen training programs focused on climate change awareness and coping strategies for cassava farmers. Extension agents and meteorologists can use various media channels such as farm demonstrations, seminars, radio, TV, and social media to disseminate this vital information.

Implementing substantive credit schemes provided by the government to support cassava farmers in enhancing their adaptation strategies. These schemes should be designed to be accessible, affordable, and readily available to farmers. The government should facilitate the availability of improved cassava varieties that are highly tolerant and resistant to the impacts of drought and floods. These varieties, along with modern cultivation techniques, should be made accessible to farmers through research institutes and the Ministry of Agriculture. The costs of improved varieties and planting materials should also be subsidized by the government to the farmers. Proper implementation of these policy actions can help cassava farmers better adapt to climate change, enhance their productivity, and ultimately improve their livelihoods.

5 Limitations and future research

The study focuses exclusively on Southwest Nigeria, which may limit the generalizability of the findings to other regions with different climate conditions, agricultural practices, or socio-economic factors. Other areas may experience varying challenges and opportunities regarding climate change adaptation. Therefore, future research could explore climate change adaptation strategies in different geographical regions or among different crop systems by examining the opportunity cost and productivity of the farmers.

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Declarations

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