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Research Article

Building Climate Resilience Using Improved Cassava Planting Materials Among Stallholder Cassava Producers in Cameroon

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Abstract

Climate change represents one of the most pressing challenges of the 21st century, disproportionately affecting rural communities reliant on agriculture for their livelihoods. To address the urgency of climate change in SSA, the technologies used must be accessible and easy to adopt. This study, based on a survey of 1,233 cassava producers in Cameroon, analyzes the effect of adopting improved cassava planting material (ICPM) on climate resilience. The econometric approach employed is a recursive bivariate probit model, which allows for the estimation of marginal effects and treatment effects. The results reveal a positive effect of ICPM adoption on resilience to drought and flood shocks. To be precise, it emerges that the probability of farmers in the sample being affected by floods decreased by an average of 30% due to ICPM adoption in anticipation of drought. The probability of farmers who adopted ICPM being affected by floods decreased by an average of over 35% due to their adoption of ICPM in anticipation of drought. The probability of farmers in the sample being affected by drought decreased by nearly 15% due to ICPM adoption in anticipation of floods. The probability of farmers who adopted ICPM being affected by drought decreased by an average of over 10% due to their adoption of ICPM in anticipation of floods. Access to electricity and the producer's experience in agriculture are identified as the main factors influencing ICPM adoption. Consequently, several recommendations are made to improve the adoption of quality seeds and mitigate the impacts of climate change-related shocks.

Keywords

Adoption, Quality Seeds, Cassava, Climate Resilience, Drought, Flood

1. Introduction

Climate change represents one of the most pressing challenges of the 21st century, disproportionately affecting rural communities reliant on agriculture for their livelihoods [1, 2]. It is primarily manifested through natural disasters

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(floods), increased rainfall variability, and episodes of drought [3-5]. Additionally, temperatures combined with humidity promote the development of certain diseases, while prolonged drought leads to water stress and, consequently, poor plant development [6]. Global warming is thus one of the most significant causes of agricultural destruction and declining production [7], acting as a catalyst for the expansion of poverty and famine. For instance, the poverty rate in Kenya was estimated at 36% in 2016, with 80% concentrated in the arid northeastern region [8]. In Cameroon, the northern zone is the most arid and the epicentre of food insecurity, with an average prevalence rate of 10% in each of the three regions of this area [9].

Although previous studies have prescribed climate-resilient agricultural technologies to African producers [10, 11], Africa remains one of the geographic regions in the world where the impact of climate change is still highly concerning [1, 12]. Indeed, agricultural production in most countries in sub-Saharan Africa (SSA) continues to be heavily dependent on climate conditions [13, 14]. Moreover, SSA remains one of the few regions globally where more than half of the population relies on agriculture for their livelihoods, particularly due to its significant contribution to employment, food security, and national economies [15]. Any significant alteration in climatic factors (rainfall, temperatures) is therefore likely to jeopardize agricultural production and, consequently, the well-being of millions of people. This situation is further exacerbated by security instabilities, such as the war in Ukraine, which has disrupted supply chains and significantly impacted the prices of cereals, fertilizers, and energy [16].

Investment in research and development has led to the creation of techniques and technologies capable of reducing the dependence of agricultural activities on climatic factors. In the contemporary era, dominated by electronics, the use of mechanization, artificial intelligence (AI), drones, and blockchain enables real-time, precise understanding and meeting of the needs of agricultural farms [17]. However, the adoption of these technologies requires significant financial resources and capabilities, which are often lacking in sub-Saharan Africa (SSA). SSA is known for having the highest poverty rates globally [18, 19], with agriculture dominated by smallholder farmers in rural areas characterized by low education levels, poor infrastructure, and limited access to financial services [20-22]. Furthermore, agriculture, often considered the best means to escape poverty [8], remains extensive in SSA, with production increases achieved through land expansion rather than improved yields. This results in low productivity, limited use of modern technologies, and high climate dependence. To address the urgency of climate change in SSA, the technologies used must be accessible and easy to adopt. The adoption of "low-tech" solutions could facilitate a gradual transition to more advanced, "high-tech" innovations while mitigating the impacts of climate change.

In tropical regions, cassava is the most important crop among roots and tubers [23]. In Cameroon, for instance, cassava ranks first in terms of production and consumption among roots and tubers. Its production in 2020 was estimated at approximately 5.5 million tons, with an annual consumption of 100 kg per person [24, 25]. Cassava is one of the few crops grown across all agroecological zones in the country and serves as a cornerstone of food security and rural income. However, cassava yields in SSA, including Cameroon, are the lowest globally [26, 27], exacerbated by rainfall variability, prolonged droughts, and climate-related diseases [28]. In response to these challenges, the adoption of improved cassava planting materials (ICPM) emerges as a promising strategy to enhance the climate resilience of smallholder farmers. These seeds, selected for their environmental stress tolerance and high yield potential, could mitigate the effects of climate change while improving productivity and livelihoods [27, 29]. However, empirical literature on the role of this technology in climate resilience remains limited. Additionally, little is known about how the adoption of quality seeds amplifies or reduces the role of its covariates in climate resilience. This gap leads us to address the following questions: i) What is the effect of ICPM adoption on climate resilience in Cameroon? ii) How does ICPM adoption influence the determinants of climate resilience in Cameroon?

2. Literature Review

Resilience refers to the ability of an entity to absorb shocks while maintaining its core functions [30]. Following any shock, resilience involves ad-hoc reorganization. The analysis of climate resilience in an agricultural context has been the subject of numerous studies documented in the literature. These studies have revealed that climate resilience depends on several factors, including the adoption of new agricultural practices, improved water resource management, and adjustments to farming schedules [1, 2, 31]. In this vein Marie et al. [32] analysed the factors influencing adaptation to climate change in Ethiopia. Using primary data collected from farmers and metadata from previous publications, they employed logit models to assess the role of socio-economic characteristics of farming households and the adoption of certain farming practices. They found that low yields, severe soil erosion, and water shortages were the main climate-related agricultural challenges. To mitigate these issues, farmers adopted techniques such as intercropping, adjusting farming schedules, using improved seeds, soil and water conservation methods, and irrigation. However, the authors did not analyse which practices were most effective. This limitation was addressed by Kim et al. [33], who estimated the economic impact of climate change on rice production in Cambodia. Their empirical evidence showed that rice production would be severely affected by climate change, with irrigation identified as the most accessible adaptation strategy.

Recognizing that the impact of climate change depends on the adaptation strategies adopted by farmers, Khanal et al. [34] studied the role of climate change adaptation strategies on agricultural productivity in Nepal. Using simultaneous equations estimated through the endogenous switching regression (ESR) method, they examined both the factors influencing the adoption of adaptation strategies and their effects on productivity. They concluded that adaptation strategies enhance productivity, with soil and water management practices having the greatest impact, followed by adjustments to farming schedules.

In a recent study, Sertse et al. [2] examined the perceptions and adaptation strategies of farming households in Ethiopia. They found that the main climate risks reported by farmers were drought, floods, and increased disease prevalence. The most widely adopted adaptation strategies included crop diversification (99%), mulching (88%), soil and water conservation practices (78%), and alternative tillage methods (74%). In contrast, the use of improved seeds (27%), tree planting (26%), intercropping (12%), and household-level farming practices (3%) were the least adopted. Access to credit and education were identified as key factors influencing adaptation strategies. Overall, adaptation strategies in developing countries rely primarily on traditional techniques, while studies in developed countries highlight more technologically advanced approaches.

Gatto et al. [35] explored how crop resilience contributes to household resilience in extreme climate conditions. Focusing on cassava and sweet potato in the aftermath of Super Typhoon Ompong, which devastated northern Philippines in 2018, they used probit and propensity score matching (PSM) models. They found that, as underground crops, cassava and sweet potato helped restore production systems after major natural disasters, reducing the need for negative adaptation strategies such as depleting household savings or seeking help from neighbours and friends.

3. Understanding the Role of Quality Seed Adoption in Climate Resilience of Developing Countries

The theoretical debate on adaptation strategies to climate change divides researchers into two main camps. The first argues that behavioural theories best explain environmentally related behaviours [36-38], while the second asserts that rationality based on the homo oeconomicus assumption is more appropriate [2, 31, 39]. To formulate effective climate policies, a clear understanding of decision-making processes in climate change adaptation is essential. This contribution focuses on quality seeds as a climate change adaptation strategy, employing a hybrid analytical approach that combines behavioural and rational perspectives.

Suppose the seed market consists of two varieties of seeds: the traditional variety (M_0) and the improved variety (M_1), with P_0 and P_1 being their respective prices. Farmers typically obtain (M_0) either i) from their own farm from the previous agricultural season, ii) as a gift from a community member, or, to a lesser extent, iii) through purchase from a supplier or another farmer (this is particularly true for cassava, which is vegetatively propagated). In contrast, M_1 is generally obtained through purchase (in exceptional cases, M_1 may be provided as a donation by public administrations, NGOs, or producer cooperatives). We can therefore assume that, under common practices, $P_1 \geq P_0$. Agricultural production in sub-Saharan Africa (SSA) is predominantly family-based. In this context, production is typically allocated across multiple purposes, including self-consumption, commercialization, and processing. The objectives of smallholder farmers are thus heterogeneous: economic (profit maximization), socio-cultural (maximization of social well-being) [40], and environmental (climate resilience). The farmer's utility would then depend on the satisfaction of three components: i) technical (yield, farm size), ii) socio-cultural (flavour, colour, texture, etc.), and iii) climatic (resilience to drought, floods, and diseases). The utility derived from using variety k can therefore be expressed as the result of three qualities:

$$U_k = \mu_k QT + \varphi_k QSC + \sigma_k QC \quad (1)$$

Here, QT, QSC and QC refer to the technical, socio-cultural, and climatic qualities of the seeds, respectively, while μ_k, φ_k and σ_k are the respective weights assigned to these qualities for variety k={M_0; M_1}. It has been observed that, in some cases, even when availability and accessibility are equal, some farmers prefer the traditional variety (M_0) [40]. Since the main advantage of this variety lies in its organoleptic characteristics, we can deduce that the weight of socio-cultural qualities for traditional seeds is greater than that for improved seeds. This behaviour is best explained by social learning theory, which highlights the predominant role of models (whom farmers imitate) in society [41]. We can thus derive the following relationship:

$$\varphi_{M_0} \geq \varphi_{M_1} \quad (2)$$

Given that improved seeds are generally developed to address food security issues, particularly by ensuring availability, they are primarily characterized by their high yield. We can therefore deduce that the weight of technical qualities for improved seeds is greater than that for traditional seeds. This leads to the following relationship:

$$\mu_{M_1} \geq \mu_{M_0} \quad (3)$$

Previous studies have found that smallholder farmers in Africa employ multiple techniques to mitigate the impact of climate change. However, the adoption of improved seeds as a means of climate resilience is uncommon [2, 34]. Consequently, the choice of climate change adaptation strategies is considered only after addressing socio-cultural and technical compliance issues. The adoption of seeds for climate resilience would thus result from the pursuit of an optimal choice among several adaptation strategies. In this case, the farmer's perception also plays a significant role in determining the best adaptation strategy. For example, a farmer might choose improved seeds over methods such as mulching or adjusting farming schedules if they perceive this technology as the most effective. We can therefore derive the following relationship:

$$\varphi_k \geq \mu_k \ \geq \ \sigma_k \quad (4)$$

This relationship (4) reflects the idea that farmers prioritize seeds that meet their cultural needs. Once cultural characteristics are ensured, farmers focus on productivity and climate resilience, respectively. For instance, a farmer who grows cassava for self-consumption will prioritize varieties with desirable consumption traits. Climate adaptability becomes a criterion only after potential productivity is considered. Let U_0 and U_1 represent the indirect utilities associated with M_0 and M_1, respectively. According to the random utility model, a farmer adopts M_1 if and only if the expected indirect utility from M_1 exceeds that from M_0. In other words, the adopted variety is the one with the highest aggregated utility across the three components:

$$U_{M_1} > U_{M_0} \rightarrow U_{QT_{M_1}} + U_{QC_{M_1}} + U_{QSC_{M_1}} > U_{QT_{M_0}} + U_{QC_{M_0}} + U_{QSC_{M_0}} \quad (5)$$

After identifying their preference, the farmer must allocate their available resources (R). These resources are allocated either exclusively to M_0, exclusively to M_1, or divided between M_0 and M_1. The budget constraint is expressed as:

$$R = P_1 M_1 + P_0 M_0 \quad (6)$$

The farmer's optimization problem can be written as:

$$Max\ U = \mu QT + \varphi QSC + \sigma QC \quad (7)$$

Subject to

$$R = P_1 M_1 + P_0 M_0$$

$$\varphi_{M_0} \geq \ \varphi_{M_1}$$

$$\mu_{M_1} \geq \mu_{M_0}$$

$$\varphi \geq \mu \geq \ \sigma$$

In reality, utility is not directly observable. What is observable is adoption. This can be modelled as:

$$Adopt^* = \gamma X + \ \varepsilon \quad (8)$$

Here, $Adopt^*$ is the latent adoption variable, taking the value 1 if the household uses improved seeds and 0 otherwise. γ is a vector of parameters, X is the matrix of explanatory variables, and ϵϵ is the vector of stochastic terms. The adoption of agricultural innovations could have an amplifying or reducing effect on the determinants of resilience. For example, in the absence of a framework to leverage them, education or access to information and communication technologies (ICT) may initially have a negligible role in climate resilience. Consequently, the adoption of an innovation can enhance the expression of covariates. For instance, when a farmer adopts an innovation like improved cassava planting materials (ICPM), certain previously unexpressed skills may be deployed. Continuing with the previous example, a farmer with access to ICT or a sufficient level of education can make better use of innovations due to their knowledge or access to information. They might, for example, test shared experiences related to improved seeds received through social networks. Resilience can thus be modelled as:

$$Resilience = \alpha + \beta\ Adopt + \left(1 + \tau_{adop}\right)\rho M + \ \delta Z + \ w_i \quad (9)$$

Here, α is a constant, $\beta, \rho, and\ \delta$ are parameters associated with explanatory variables, AdoptAdopt is the adoption variable, τadoptτadopt is the amplifying (or reducing) effect linked to adoption, M is a matrix of covariates influenced by adoption, Z is a matrix of other explanatory variables, and w_i is the stochastic term. In the absence of adoption ($Adopt = 0$), equation (9) becomes:

$$Resilience = \alpha + \rho M + \ \delta Z + \ w_i \quad (10)$$

4. Methodological Approach

4.1. Data

The data used in this study were collected in 2019 regarding the 2017-2018 agricultural season. The data collection was led by the International Institute of Tropical Agriculture (IITA). A multi-stage sampling technique was employed, with regions, departments, and villages selected in a structured manner. Following a consultation with Cameroon's Ministry of Agriculture (MINADER), we identified the localities that were affected by climate shocks (drought and/or flooding) during the 2017-2018 agricultural season. A sample was then constructed based on the proportion of cassava producers affected by these climate shocks (see Table 1 for the sample distribution by region). The Centre, East, Littoral, and South regions were chosen for the study. These regions were selected because they are recognized as the main cassava production basins in Cameroon [42, 43]. The dataset initially included 1,233 cassava-producing households. However, for the purposes of this study, we retained 1,198 households, excluding those with missing information on key factors such as the type of planting material used, production levels, farm size, and others.

Table 1. Distribution of the sample in the studied area.

Region	Freq.	Percent	Cum.
Centre	785	65.53	65.53
East	79	6.59	72.12
Littoral	11	0.92	73.04
South	323	26.96	100.00
Total	1198	100.00	

In this study, the climatic factors considered are drought and floods. Aligning with the definition by Folke et al. [30], the resilience offered by the adoption of improved cassava planting materials (ICPM) to drought or floods refers to its ability to maintain or recover acceptable productivity when exposed to water scarcity (drought) or excess water (flooding).

We rely on farmers' perceptions and assign a score of 1 if the farmer reports that their production was adversely affected by drought or floods, and 0 otherwise. It is important to note that the average cassava production cycle is 12 months [44]. During this period, cassava farms in the study area are exposed to various forms of water stress (drought, heavy rainfall). Therefore, the occurrence of drought and flooding is assumed a priori.

In most African countries, including Cameroon, the agricultural sector is dominated by smallholder farmers. There is generally no binding legislation related to agricultural value chains. Consequently, many farmers perform multiple roles in the cassava value chain, including tuber production, marketing in rural or urban markets, and artisanal processing of part (or all) of their production (into gari, flour, starch, etc.) for sale. We assume that a farmer whose primary goal is processing may have different seed preferences compared to those focused on self-consumption or commercialization. For example, they may prioritize traits such as starch content, fibre content, or cyanide levels.

4.2. Empirical Modelling

To estimate the effect of innovation adoption on resilience, improved cassava planting materials (ICPM) were considered as the innovation, while the compromise of production due to climatic shocks (drought and floods) was used to measure climate resilience. The variables related to climate resilience take dichotomous values: 1 if production was compromised by the considered climatic shock, and 0 otherwise. The issue of the impact of technology adoption has been extensively addressed within the framework of treatment effects as defined by Heckman ([45]) [40, 46, 47]. Previous studies have taken care to correct for endogeneity and selection biases using methods such as propensity score matching (PSM), endogenous switching regression (ESR), and instrumental variable modelling, among others. However, earlier work has overlooked cases where: i) a binary treatment variable influences a binary outcome variable, ii) beyond observable selection biases, unobservable selection biases (e.g., related to commitment or willingness) are also possible [48], and iii) the relationship between the treatment variable and the outcome variable may be recursive. The impact of technology adoption on climate resilience, using a structural approach, can be modelled as follows:

$$Adopt^{*} = \gamma X + \varepsilon \tag{11}$$

$$Choc\ clim_i = \alpha + \beta Adopt_i + \delta Z + w_i \tag{12}$$

Here, α is a constant to be estimated, Z is a matrix of explanatory variables, and w_i is the stochastic term. Since the adoption variable is an explanatory variable in equation (12), a correlation between the terms ε_i and w_i is possible, leading to an endogeneity problem. However, it is not always necessary to account for the endogeneity of the adoption factor [49, 50]. If recursiveness in the relationship between the treatment variable (adoption) and the outcome variable (climatic shock) is theoretically established, the causal effect of innovation adoption on climate resilience can be modelled as follows:

$$\begin{cases} Adoption_i = \begin{cases} 1\ si\ Adoption_i^{*} > 0 \\ 0\ Sinon \end{cases} with\ Adoption_i^{*} = \rho + \gamma_i X_i + \varepsilon_i \\ Choc\ clim_i = \begin{cases} 1\ si\ Choc\ clim_i^{*} > 0 \\ 0\ Sinon \end{cases} with\ Choc\ clima_i^{*} = \alpha + \beta \widehat{Adop} + \delta_i Z_i + w_i \end{cases} \tag{13}$$

Model (13) is a recursive bivariate probit model. For robustness, we employed both bivariate probit and recursive bivariate probit models. This approach allows us to assess the sensitivity of our results in the case of a non-recursive relationship between ICPM adoption and climate resilience, thereby ensuring the robustness of the observed results.

5. Results

5.1. Descriptive Statistics Analysis

The descriptive statistics of cassava-producing households are summarized in Table 2. The sample consists of nearly equal proportions of adopting (49%) and non-adopting (51%) households. Household heads are relatively mature, with an average age of over 52 years, and no significant difference between adopters and non-adopters. Nearly 60% of households are headed by males. Significant differences between adopters and non-adopters are observed for the following variables: access to electricity, sheep and goat farming, household size, yield, and farm size.

While nearly 70% of adopting households have access to electricity, only about half of non-adopting households have such access. There is a significant difference at the 10% level between adopters and non-adopters regarding household size. Adopting households have an average of 5 members, while non-adopting households have slightly fewer. Approximately 5% of adopting households practice sheep and goat farming, compared to only 1% of non-adopting households. About 15% of farmers process their cassava into flour, but the proportion of non-adopters engaging in this activity is significantly lower at 10%.

Regarding technical factors, there is a significant difference at the 1% level between adopters and non-adopters. The average cassava farm size for adopters exceeds 8,000 m², while for non-adopters, it is less than 7,500 m². In terms of yield, adopters achieve over 15 tons per hectare, compared to less than 12 tons per hectare for non-adopters. Farmers report an average experience of nearly 25 years in both general agriculture and specific cassava production. Approximately 30% of cassava producers reported their production being compromised by floods, while less than 10% reported drought as a factor compromising their production.

Table 2. *Descriptive Statistics of Producer Household Characteristics.*

Variable	Description	Non-Adopters (51.25%)	Adopters (48.75%)	Difference	Standard Error
Access to Electricity	1 if the household has access to electricity; 0 otherwise	0.494	0.692	-0.197***	0.028
Age	Number of years of the household head	52.692	52.143	0.549	0.029
Gender	1 if the household head is male; 0 otherwise	0.583	0.555	0.029	0.177
Household Size	Number of people in the household	4.838	5.132	-0.293*	0.177
ICT (Phone, Radio, TV, etc.)	1 if the household has access; 0 otherwise	0.868	0.901	-0.034	0.018
Sheep and Goat Farming	1 if the household practices this type of farming; 0 otherwise	0.019	0.044	-0.025**	0.010
Gari Production	1 if the household also produces gari; 0 otherwise	0.013	0.018	-0.005	0.007
Cassava Flour Production	1 if the household also produces cassava flour; 0 otherwise	0.127	0.163	-0.036*	0.022
Access to Credit	1 if the household has access to credit; 0 otherwise	0.301	0.295	0.006	0.027
Full Harvest	1 if the household harvests the entirety of its production; 0 otherwise	0.335	0.368	-0.033	0.028
Production Cycle	Duration of the production cycle in months	12.365	12.213	0.151	0.163
Starch Production	1 if the household also produces starch; 0 otherwise	0.002	0.009	-0.007	0.005
Food Insecurity	1 if the household experienced food shortages in the past year; 0 otherwise	1.647	1.689	-0.041	0.028
Farming Experience	Number of years engaged in agricultural activities	24.052	23.884	0.167	0.919
Cassava Production Experience	Number of years engaged in cassava production	24.637	24.814	-0.176	10.117
Drought	1 if the household perceived negative effects of drought on production; 0 otherwise	0.026	0.024	0.002	0.009
Flood	1 if the household perceived negative effects of floods on production; 0 otherwise	0.287	0.291	-0.005	0.026
Yield	In tons per hectare	11.063	15.837	-4.773***	0.565

Variable	Description	Non-Adopters (51.25%)	Adopters (48.75%)	Difference	Standard Error
Farm Size	In hectares	0.820	0.734	0.086***	0.020

Notes: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

5.2. Econometric Analysis and Discussion

Table 3 presents the estimation of the effect of adopting improved cassava planting materials (ICPM) on resilience to floods. The results were obtained using a recursive bivariate probit model (rbiprobit). Columns (2) and (4) report the estimation of the determinants of ICPM adoption, while columns (1) and (3) report the estimation of factors influencing the occurrence of flood shocks. The difference between models 1 and 2 lies in the inclusion of drought as a factor influencing ICPM adoption. A heteroscedasticity test was conducted on the flood resilience equation, revealing a potential risk of heteroscedasticity bias (see Table A2). To address this, robust regression models were used. Additionally, Ramsey's Regression Equation Specification Error Test (RESET) was performed, confirming no issues related to model specification or omitted variables. Thus, the chosen regression model is appropriate for analysing the data.

Of the 13 variables used to model ICPM adoption, only four were significant at the 10% level or lower. Specifically, access to electricity has a positive and significant parameter at the 1% level in both adoption models, indicating that access to electricity increases the likelihood of adopting ICPM. This result can be attributed to the benefits of electricity access, such as improved communication (via radio, television, etc.), which enhances farmers' awareness of the advantages of quality seeds [51]. Additionally, electricity access may enable additional income-generating activities (e.g., selling products requiring refrigeration), facilitating economic access to quality seeds.

When drought perception is included in the adoption model, food insecurity has a positive and significant effect at the 10% level on ICPM adoption. This suggests that in drought-prone contexts, food scarcity increases the likelihood of adopting ICPM. This reflects the reality that the co-occurrence of famine and drought motivates farmers to seek climate-resilient solutions, including ICPM adoption. Farmers perceive ICPM as a means to escape famine in the face of climate change. This idea is further supported by the positive effect of drought perception on ICPM adoption.

Furthermore, in both models, yield has a positive effect on ICPM adoption. This can be explained by social learning theory, as farmers tend to adopt seeds that have proven successful for others in their community. This result could also create a virtuous cycle where adoption increases yield, further encouraging adoption.

Of the 10 variables used to model the occurrence of flood-related shocks to cassava production in Cameroon, five are significant at the 10% level or lower. When drought is considered as a factor influencing adoption, the parameter for the "adoption" variable is negative and significant at the 10% level. However, when drought is omitted, the effect of ICPM adoption is not significant. This suggests that ICPM adoption reduces the likelihood of farmers experiencing negative flood impacts, with drought acting as a mediator in the relationship between adoption and flood resilience. In other words, drought influences both adoption and resilience, and ICPM adoption becomes significant only when motivated by drought. This result indicates that quality seeds may be more resistant to water stress (excess water), improving crop survival during floods. Additionally, the adoption of quality seeds may be associated with improved agricultural practices (e.g., better soil or water management), enhancing overall farm resilience [52]. This finding confirms that quality seeds are an effective means of flood resilience, aligning with previous studies on the benefits of quality seeds in climate change contexts [32, 46].

Moreover, the parameter for farmer age is negative and significant at the 5% level, indicating that older farmers are more resilient to floods. This may reflect the accumulated experience and knowledge of older farmers, enabling them to better anticipate and manage climate risks such as floods.

Household size has a negative and significant parameter at the 1% level, indicating a positive effect on flood resilience. Previous studies have shown that farmers often adopt soil conservation methods (e.g., tillage, mulching, manual drainage) to mitigate climate shocks [1, 2, 31]. In low-income countries, these strategies require significant labour, making family labour a key factor in flood adaptation.

The ICT variable has a negative and significant parameter at the 5% level, indicating a positive effect on flood resilience. This result can be attributed to the role of ICT in disseminating weather information and flood adaptation strategies, enabling better anticipation and management of climate risks.

Finally, the parameter for cassava processing into gari is positive and significant, indicating a negative effect of this practice on flood resilience. This suggests that processing cassava into gari increases the risk of flood-related damage to tuber production. This may be due to the use of varieties suitable for gari processing (e.g., high starch content, low fibre, low cyanide) but sensitive to climatic factors [53]. The models demonstrate robustness, as indicated by the RESET test and AIC values.

Table 3. Estimation Results of the Effect of ICPM Adoption on Resilience to Floods (rbiprobit).

Variables	Model 1 (1) Flood	(2) Adoption	Model 2 (3) Flood	(4) Adoption
Full Harvest		0.0421		0.0365
		(0.0898)		(0.0942)
Production Cycle		-0.00720		-0.00403
		(0.0179)		(0.0183)
Starch Production		0.389		0.429
		(0.854)		(0.829)
Access to Electricity	0.0968	0.537***	0.153	0.539***
	(0.184)	(0.0955)	(0.173)	(0.0950)
Food Insecurity		0.153*		0.157
		(0.0891)		(0.0959)
Farming Experience		0.00323		0.00391
		(0.00509)		(0.00507)
Age	-0.00715**	-0.00239	-0.00749**	-0.00277
	(0.00352)	(0.00386)	(0.00347)	(0.00390)
Gender	0.109	0.0332	0.115	0.0356
	(0.0907)	(0.0929)	(0.0920)	(0.0930)
Cassava Production Experience		0.00355		0.00371
		(0.00301)		(0.00313)
Household Size	-0.0602***	-0.00190	-0.0619***	-0.00286
	(0.0159)	(0.0141)	(0.0157)	(0.0142)
Drought		0.531*		
		(0.283)		
ICT	-0.312**	0.122	-0.317**	0.117
	(0.129)	(0.138)	(0.131)	(0.138)
Yield		0.0457***		0.0461***
		(0.00658)		(0.00586)
Adoption	-0.909*		-0.708	
	(0.534)		(0.547)	
Sheep and Goat Farming	-0.163		-0.161	
	(0.232)		(0.248)	
Gari Production	1.070***		1.113***	
	(0.336)		(0.344)	
Cassava Flour Production	-0.200		-0.200	
	(0.126)		(0.133)	
Access to Credit	-0.123		-0.129	

Variables	Model 1		Model 2	
	(1)	(2)	(3)	(4)
	Flood	Adoption	Flood	Adoption
	(0.0961)		(0.0993)	
Constant	-0.0202	-1.234***	0.0515	-1.292***
	(0.305)	(0.441)	(0.309)	(0.417)
Atanrho	-0.740		-0.542	
	(0.574)		(0.468)	
AIC	2050.787		2052.18	
Generalised RESET test; chi2(2)	0.83		0.37	
Prob > chi2	0.6614		0.8292	
Observations	1198	1198	1198	1198

Notes: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are reported in parentheses. AIC: Akaike Information Criterion. RESET test: Regression Equation Specification Error Test.

Table 4 presents the estimation of the effect of adopting improved cassava planting materials (ICPM) on resilience to drought using the recursive bivariate probit model (rbiprobit). Robust estimation was employed due to the potential for heteroscedasticity bias in the model variables (see Appendix Table A2). Models 1 and 2 highlight the role of floods in the estimation. The results of the various tests are similar to those in Table 2. Additionally, the correlation coefficient between the errors is significant and negative, indicating complex interrelationships between the endogenous variables and an inverse relationship in the unobserved disturbances of the two equations.

In this case, regardless of whether floods are included in the model, ICPM adoption has a negative and significant parameter at the 1% level. This result reflects the reality that ICPM adoption reduces the likelihood of drought compromising cassava production. Ultimately, ICPM not only enhances productivity [29, 46] but also ensures resilience in drought conditions. This may be due to seeds with deeper or more efficient root systems for water absorption, enabling better resistance to dry periods.

Unlike the case where floods are the outcome variable, here the processing of cassava into gari has a negative and significant parameter at the 1% level. This indicates that processing cassava into gari reduces the probability of drought compromising cassava production. This result suggests that gari producers employ drought-resilient practices but are less resilient to floods. This may reflect the reality that, in the study area, drought is a more significant threat than floods, prompting farmers to prioritize drought resilience.

Furthermore, in addition to access to electricity and yield as determinants of ICPM adoption, farming experience has a positive and significant parameter at the 1% level. This result indicates that more experienced farmers are more likely to adopt ICPM. This can be attributed to the fact that experienced farmers have a better understanding of the risks and opportunities associated with new technologies, reducing their reluctance to adopt innovations.

Table 4. *Estimation Results of the Effect of ICPM Adoption on Resilience to Drought (rbiprobit).*

Variables	Model 1		Model 2	
	(1)	(2)	(3)	(4)
	Drought	Adoption	Drought	Adoption
Full Harvest		0.0379		0.0313
		(0.0955)		(0.0958)

Variables	Model 1 (1) Drought	(2) Adoption	Model 2 (3) Drought	(4) Adoption
Production Cycle		-0.00141		0.000154
		(0.0164)		(0.0164)
Starch Production		1.154		1.179
		(0.761)		(0.786)
Access to Electricity	-0.168	0.570***	-0.153	0.558***
	(0.188)	(0.0935)	(0.192)	(0.0933)
Food Insecurity		0.0922		0.0889
		(0.0951)		(0.0959)
Farming Experience		0.00925***		0.00962***
		(0.00312)		(0.00316)
Age	0.00368	-0.00266	0.00358	-0.00237
	(0.00538)	(0.00394)	(0.00549)	(0.00397)
Gender	0.0178	0.0455	0.0107	0.0403
	(0.150)	(0.0924)	(0.153)	(0.0923)
Cassava Production Experience		0.00285		0.00287
		(0.00322)		(0.00326)
Household Size	0.0356	-0.00666	0.0369	-0.00345
	(0.0234)	(0.0146)	(0.0236)	(0.0144)
Flood		-0.135		
		(0.102)		
ICT	0.381	0.133	0.378	0.147
	(0.346)	(0.140)	(0.349)	(0.139)
Yield		0.0440***		0.0434***
		(0.00591)		(0.00591)
Adoption	-1.206***		-1.125***	
	(0.412)		(0.431)	
Sheep and Goat Farming	-0.00733		0.00595	
	(0.415)		(0.420)	
Gari Production	-4.127***		-4.101***	
	(0.222)		(0.233)	
Cassava Flour Production	-0.485		-0.496	
	(0.309)		(0.315)	
Access to Credit	-0.0696		-0.0645	
	(0.164)		(0.168)	
Constant	-2.804***	-1.285***	-2.806***	-1.376***
	(0.516)	(0.380)	(0.522)	(0.374)

Variables	Model 1 (1) Drought	(2) Adoption	Model 2 (3) Drought	(4) Adoption
Atanrho	-1.013***		-0.916**	
	(0.391)		(0.380)	
AIC	1262.801		1262.6	
Generalised RESET test; chi2(2)	0.37		0.20	
Prob > chi2	0.8292		0.9064	
Observations	1198	1198	1198	1198

Notes: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are reported in parentheses. AIC: Akaike Information Criterion. RESET test: Regression Equation Specification Error Test.

Table 5 presents the estimation of the effect of adopting improved cassava planting materials (ICPM) on resilience to floods using the bivariate probit model (biprobit). Columns (2) and (4) report the estimation of the determinants of ICPM adoption, while columns (1) and (3) report the estimation of factors influencing the occurrence of flood shocks on cassava tuber production. Models 1 and 2 highlight the role of drought as a factor influencing adoption.

The Akaike Information Criterion (AIC) for modelling the relationship between adoption and flood resilience takes the values 2050.787 and 2052.18 for both the recursive bivariate probit model and the standard bivariate probit model, respectively. This statistic indicates that both models achieve a similar balance between data fit and complexity. Furthermore, the results obtained from both models are highly consistent, demonstrating the robustness of the findings.

The similarity in results across the two models reinforces the reliability of the conclusions drawn regarding the impact of ICPM adoption on flood resilience. This robustness check ensures that the observed effects are not artifacts of the specific modelling approach but reflect genuine relationships in the data.

Table 5. Estimation Results of the Effect of ICPM Adoption on Resilience to Floods (biprobit).

Variables	Model 1 (1) Flood	(2) Adoption	Model 2 (3) Flood	(4) Adoption
Full Harvest		0.0421		0.0365
		(0.0898)		(0.0942)
Production Cycle		-0.00720		-0.00403
		(0.0179)		(0.0183)
Starch Production		0.389		0.429
		(0.854)		(0.829)
Access to Electricity	0.0968	0.537***	0.153	0.539***
	(0.184)	(0.0955)	(0.173)	(0.0950)
Food Insecurity		0.153*		0.157
		(0.0891)		(0.0959)
Farming Experience		0.00323		0.00391

Variables	Model 1 (1) Flood	 (2) Adoption	Model 2 (3) Flood	 (4) Adoption
		(0.00509)		(0.00507)
Age	-0.00715**	-0.00239	-0.00749**	-0.00277
	(0.00352)	(0.00386)	(0.00347)	(0.00390)
Gender	0.109	0.0332	0.115	0.0356
	(0.0907)	(0.0929)	(0.0920)	(0.0930)
Cassava Production Experience		0.00355		0.00371
		(0.00301)		(0.00313)
Household Size	-0.0602***	-0.00190	-0.0619***	-0.00286
	(0.0159)	(0.0141)	(0.0157)	(0.0142)
Drought		0.531*		
		(0.283)		
Yield		0.0457***		0.0461***
		(0.00658)		(0.00586)
ICT	-0.312**	0.122	-0.317**	0.117
	(0.129)	(0.138)	(0.131)	(0.138)
Adoption	-0.909*		-0.708	
	(0.534)		(0.547)	
Sheep and Goat Farming	-0.163		-0.161	
	(0.232)		(0.248)	
Gari Production	1.070***		1.113***	
	(0.336)		(0.344)	
Cassava Flour Production	-0.200		-0.200	
	(0.126)		(0.133)	
Access to Credit	-0.123		-0.129	
	(0.0961)		(0.0993)	
Athrho	-0.740		-0.542	
	(0.574)		(0.468)	
Constant	-0.0202	-1.234***	0.0515	-1.292***
	(0.305)	(0.441)	(0.309)	(0.417)
AIC	2050.787		2052.18	
Observations	1198	1198	1198	1198

Notes: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are reported in parentheses. AIC: Akaike Information Criterion.

Table 6 presents the estimation of the effect of adopting improved cassava planting materials (ICPM) on resilience to drought using the bivariate probit model (biprobit). Columns (2) and (4) report the estimation of the determinants of ICPM adoption, while columns (1) and (3) report the estimation of factors influencing the compromise of production due to drought. Models 1 and 2 highlight the role of floods as a factor influencing adoption.

The Akaike Information Criterion (AIC) for modelling the relationship between adoption and drought resilience takes the values 1262.801 and 1319.025 for the recursive bivariate probit model and the standard bivariate probit model, respectively. This statistic indicates that the recursive bivariate probit model offers a slightly better fit to the data compared to the standard bivariate probit model. However, the results from both models are not fundamentally different, suggesting an acceptable level of stability and, by extension, robustness in the causal relationship between ICPM adoption and drought resilience.

The consistency in results across the two models reinforces the reliability of the findings, confirming that ICPM adoption significantly enhances resilience to drought. This robustness check ensures that the observed effects are not dependent on the specific modeling approach but reflect a genuine relationship in the data.

Table 6. Estimation Results of the Effect of ICPM Adoption on Resilience to Drought (biprobit).

Variables	Model 1		Model 2	
	(1)	(2)	(3)	(4)
	Drought	Adoption	Drought	Adoption
Full Harvest		0.0379		0.0313
		(0.0955)		(0.0958)
Production Cycle		-0.00141		0.000154
		(0.0164)		(0.0164)
Starch Production		1.154		1.179
		(0.761)		(0.786)
Access to Electricity	-0.168	0.570***	-0.153	0.558***
	(0.188)	(0.0935)	(0.192)	(0.0933)
Food Insecurity		0.0922		0.0889
		(0.0951)		(0.0959)
Farming Experience		0.00925***		0.00962***
		(0.00312)		(0.00316)
Age	0.00368	-0.00266	0.00358	-0.00237
	(0.00538)	(0.00394)	(0.00549)	(0.00397)
Gender	0.0178	0.0455	0.0107	0.0403
	(0.150)	(0.0924)	(0.153)	(0.0923)
Cassava Production Experience		0.00285		0.00287
		(0.00322)		(0.00326)
Household Size	0.0356	-0.00666	0.0369	-0.00345
	(0.0234)	(0.0146)	(0.0236)	(0.0144)
Flood		-0.135		
		(0.102)		
Yield		0.0440***		0.0434***
		(0.00591)		(0.00591)
ICT	0.381	0.133	0.378	0.147

Variables	Model 1 (1) Drought	(2) Adoption	Model 2 (3) Drought	(4) Adoption
	(0.346)	(0.140)	(0.349)	(0.139)
Adoption	-1.206***		-1.125***	
	(0.412)		(0.431)	
Sheep and Goat Farming	-0.00733		0.00595	
	(0.415)		(0.420)	
Gari Production	-4.127***		-4.101***	
	(0.222)		(0.233)	
Cassava Flour Production	-0.485		-0.496	
	(0.309)		(0.315)	
Access to Credit	-0.0696		-0.0645	
	(0.164)		(0.168)	
Athrho	-1.013***		-0.916**	
	(0.391)		(0.380)	
Constant	-2.804***	-1.285***	-2.806***	-1.376***
	(0.516)	(0.380)	(0.522)	(0.374)
AIC	1320.158		1319.025	
Observations	1198	1198	1198	1198

Notes: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are reported in parentheses. AIC: Akaike Information Criterion.

Table 7 presents the results of the effects of ICPM adoption on the probability that climatic shocks (floods and drought) have hindered cassava tuber production.

Floods: The Average Treatment Effect (ATE) of -0.309 indicates that the probability of farmers in the sample being affected by floods decreased by an average of 30% due to ICPM adoption in anticipation of drought. The Average Treatment Effect on the Treated (ATET) of -0.364 shows that the probability of farmers who adopted ICPM being affected by floods decreased by an average of over 35% due to their adoption of ICPM in anticipation of drought. Additionally, the ATE of -0.240 suggests that the probability of farmers in the sample being affected by floods decreased by an average of nearly 25% due to ICPM adoption. This effect is almost the same for the group of adopters (ATET = -0.267).

Drought: The ATE of -0.133 indicates that the probability of farmers in the sample being affected by drought decreased by nearly 15% due to ICPM adoption in anticipation of floods. The ATET of -0.101 shows that the probability of farmers who adopted ICPM being affected by drought decreased by an average of over 10% due to their adoption of ICPM in anticipation of floods. Furthermore, the ATE of -0.117 suggests that the probability of farmers in the sample being affected by drought decreased by an average of nearly 12% due to ICPM adoption. The ATET of -0.092 indicates that the probability of farmers who adopted ICPM being affected by drought decreased by an average of 10% due to their adoption of ICPM.

These results demonstrate that ICPM adoption plays a significant role in mitigating the impact of climate-related water stress. Additionally, it is evident that drought represents the greatest concern for farmers in the sample, as the reduction in drought-related risks, while significant, is slightly lower compared to flood-related risks. This highlights the importance of ICPM as a tool for enhancing resilience to both floods and drought, with a particularly strong effect on flood resilience.

Table 7. *Estimation of Average Treatment Effects (ATE and ATET) of Adoption on Climate Factors.*

Model	Delta-method					
	Flood	**dy/dx**	**St. Err.**	**t-value**	**p-value**	**Sig**
(1)	ATE	-0.309	0.184	1.680	0.093	*.
	ATET	-0.364	0.206	1.770	0.077	*
(2)	ATE	-0.240	0.187	1.280	0.199	
	ATET	-0.267	0.202	1.320	0.186	

Model	Delta-method					
	Drought	**dy/dx**	**St. Err.**	**t-value**	**p-value**	**Sig**
(3)	ATE	-0.133	0.085	1.560	0.118	
	ATET	-0.101	0.091	1.110	0.266	
(4)	ATE	-0.117	0.081	1.430	0.152	
	ATET	-0.092	0.086	1.070	0.286	

Note: *** p<0,01, ** p<0,05, * p<0,1.

Table 8 presents the marginal effects of the explanatory factors of resilience to climate-related water stresses (drought and flooding) in the context of ICPM adoption. It can be observed, based on the first tier, that when drought is considered as a determinant of ICPM adoption, the age of the household head has the same effect with and without ICPM adoption (an additional year in the age of the household head reduces the probability of the sampled producers being affected by flooding by 0.1%). Household size exhibits a similar pattern (an additional person in the household reduces the probability of the sampled producers being affected by flooding by 1.1%). This trend is maintained with the variables "ICT" and "Gari." Moreover, the result is nearly identical when drought is considered as a determinant of ICPM adoption.

It can be observed from the second tier that only the variable "Gari" has a significant effect on resilience to drought. It emerges that when flooding is considered as a determinant of the adoption of improved cassava planting material (ICPM), dedicating part (or all) of cassava tuber production to processing into gari reduces the probability of sampled producers being affected by drought by 15% when they adopt ICPM, and by 13% when they do not adopt it. When flooding is not considered as a determinant of ICPM adoption, the effect is nearly the same.

Table 8. *Marginal Effects of the Equation s from the Recursive Bivariate Probit Model for MAPM Adoption.*

Covariates	Flooding (1)				Flooding (2)			
	With ICPM (Adoption =1)		**Without ICPM (Adoption=0)**		**With ICPM (Adoption =1)**		**Without ICPM (Adoption =0)**	
	dy/dx	**std. err.**	**dy/dx**	**std. err.**	**dy/dx**	**std. err.**	**dy/dx**	**std. err.**
Access to electricity	0.018	0.032	0.018	0.033	0.028	0.028	0.028	0.029
Age	-0.001**	0.001	-0.001**	0.001	-0.001**	0.001	-0.001**	0.001
Gender	0.021	0.017	0.021	0.017	0.021	0.017	0.021	0.017
Household size	-0.011***	0.003	-0.011***	0.003	-0.011***	0.003	-0.011***	0.003

Covariates	Flooding (1)				Flooding (2)			
	With ICPM (Adoption =1)		Without ICPM (Adoption=0)		With ICPM (Adoption =1)		Without ICPM (Adoption =0)	
	dy/dx	std. err.	dy/dx	std. err.	dy/dx	std. err.	dy/dx	std. err.
ICT (phone, radio, TV, etc.)	-0.060**	0.025	-0.059**	0.024	-0.057**	0.024	-0.057**	0.024
Sheep and goat farming	-0.031	0.045	-0.031	0.044	-0.029	0.045	-0.029	0.045
Gari	0.204***	0.065	0.202***	0.062	0.201***	0.063	0.201***	0.062
Cassava flour	-0.038	0.024	-0.038	0.024	-0.036	0.024	-0.036	0.024
Access to credit	-0.023	0.018	-0.023	0.018	-0.023	0.018	-0.023	0.018

Covariates	drought (3)				drought (4)			
	With ICPM (Adoption =1)		Without ICPM (Adoption =0)		With ICPM (Adoption =1)		Without ICPM (Adoption =0)	
	dy/dx	std. err.	dy/dx	std. err.	dy/dx	std. err.	dy/dx	std. err.
Access to electricity	-0.006	0.008	-0.005	0.006	-0.005	0.008	-0.005	0.006
Age	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Gender	0.001	0.005	0.001	0.005	0.001	0.005	0.001	0.005
Household size	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
ICT (phone, radio, TV, etc.)	0.014	0.014	0.012	0.011	0.013	0.014	0.012	0.011
Sheep and goat farming	-0.001	0.015	-0.001	0.013	0.001	0.015	0.001	0.013
Gari	-0.149***	0.049	-0.133***	0.037	-0.143***	0.046	-0.131***	0.037
Cassava flour	-0.017	0.011	-0.016	0.011	-0.017	0.011	-0.016	0.011
Access to credit	-0.003	0.006	-0.002	0.005	-0.002	0.006	-0.002	0.005

Note: (1) Model with drought control; (2) Model without drought control; (3) Model with flood control; (4) Model without flood control. Source: Authors' calculations based on 2019 survey data. *** p<0.01, ** p<0.05, * p<0.

6. Conclusion

This study examined the potential of improved cassava planting materials (ICPM) to enhance resilience to floods and drought, two key climate indicators. The analysis, based on a 2019 survey of 1,233 cassava producers with nearly equal proportions of adopters and non-adopters revealed that approximately 30% of cassava producers reported their production being compromised by floods, while less than 10% cited drought as a factor.

The findings indicate that adoption is significantly linked to social, technical, and climatic factors. Specifically: In modelling resilience to flood shocks, access to electricity, drought-related shocks, and yield are positively associated with ICPM adoption. In modelling resilience to drought shocks, access to electricity, farming experience, and yield are positively linked to ICPM adoption.

The econometric analysis, using recursive bivariate probit and standard bivariate probit models, highlights differentiated effects of ICPM adoption depending on the role of climatic factors in adoption. Adopting ICPM appears to have a positive effect on climate resilience. Specifically: The adoption variable has a negative parameter in both drought and flood shock models, indicating its potential to mitigate the impact of these shocks. Household head age, household size, and access to communication tools seem to reduce the incidence of floods. However, producing cassava for gari processing appears to increase the likelihood of flood-related shocks. Conversely, it reduces the likelihood of drought-related shocks.

The study also identifies a mediating effect of drought between ICPM adoption and flood resilience. Additionally, ICPM adoption only slightly influences its covariates in mitigating the incidence of floods and drought. This effect is particularly evident in the role of gari processing in the drought model. Key recommendations:

i) Increase Adoption Rates of Quality Seeds. to address the impact of climate change, it is crucial to improve the adoption rate of quality seeds. Strengthening the seed distribution system through public-private partnerships could play a vital role in connecting seed producers with farmers.

ii) Promote Access to Electricity. Expanding access to electricity is essential, as it facilitates the dissemination of information and knowledge, enables new income-generating activities, and ensures economic access to quality seeds. It also enhances farmers' understanding of climate shock mitigation strategies.

Invest in Role Models and Value Chains. Experienced farmers should share their knowledge with their communities to facilitate the adoption and diffusion of quality seeds. Additionally, mechanisms should be developed to encourage the processing of cassava into derived products like gari. This could increase farmers' incomes, stimulate rational decision-making, and guide them toward more precise technologies that meet their needs.

These recommendations aim to enhance climate resilience, improve livelihoods, and promote sustainable agricultural practices among cassava producers in the face of climate change.

Abbreviations

AIC	Akaike Information Criterion
ATE	Average Treatment Effect
ATET	Average Treatment Effect on the Treated
ESR	Endogenous Switching Regression
ICPM	Improved Cassava Planting Materials
ICT	Information and Communication Technology
PSM	Propensity Score Matching
RESET	Regression Equation Specification Error Test
SSA	Sub-Saharan Africa

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A1. Pearson Correlation Coefficients Between Variables.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Flooding	1.000									
(2) Access to electricity	0.073	1.000								
	(0.011)									
(3) Age	-0.069	-0.001	1.000							
	(0.031)	(0.977)								
(4) Gender	0.052	-0.004	-0.013	1.000						
	(0.071)	(0.904)	(0.677)							
(5) Household size	-0.127	0.072	-0.020	0.053	1.000					
	(0.000)	(0.013)	(0.534)	(0.066)						
(6) ICT (phone. Radio, TV, etc.)	-0.087	0.128	-0.039	0.022	0.097	1.000				
	(0.003)	(0.000)	(0.232)	(0.457)	(0.001)					
(7) Sheep and goat farming	-0.010	0.073	-0.003	0.032	0.069	0.050	1.000			
	(0.723)	(0.011)	(0.928)	(0.263)	(0.016)	(0.087)				
(8) Gari production	0.066	0.029	-0.015	-0.009	0.049	0.044	-0.022	1.000		
	(0.028)	(0.346)	(0.654)	(0.767)	(0.105)	(0.144)	(0.458)			
(9) Cassava flour production	0.006	0.040	-0.074	-0.015	0.195	0.011	0.001	0.179	1.000	

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0.848)	(0.190)	(0.028)	(0.628)	(0.000)	(0.717)	(0.973)	(0.000)		
(10) Cassava flour production	-0.052	0.059	0.007	0.064	0.113	0.099	0.028	0.080	0.089	1.000
	(0.075)	(0.047)	(0.827)	(0.029)	(0.000)	(0.001)	(0.338)	(0.009)	(0.004)	

Note: Significance threshold in parentheses.

***Table A2**. Results of Heteroscedasticity Tests.*

Breusch-Pagan/Cook-Weisberg test for heteroskedasticity	Breusch-Pagan/Cook-Weisberg test for heteroskedasticity
Assumption: Normal error terms	Assumption: Normal error terms
Variable: Fitted values of Flooding	Variable: Fitted values of Drought
H0: Constant variance	H0: Constant variance
chi2(1) = 14.55	chi2(1) = 143.91
Prob > chi2 = 0.0001	Prob > chi2 = 0.0000

***Table A3**. Direct and Indirect Effects on Drought Shocks.*

Variables	(1) Direct Effect	(2) Indirect Effect	(3) Total Effect
Full Harvest		0.000946	0.000946
		(0.00248)	(0.00248)
Production Cycle		-3.51e-05	-3.51e-05
		(0.000412)	(0.000412)
Starch Production		0.0288	0.0288
		(0.0254)	(0.0254)
Access to Electricity	-0.00606	0.0142**	0.00816
	(0.00779)	(0.00662)	(0.00597)
Food Insecurity		0.00230	0.00230
		(0.00245)	(0.00245)
Farming Experience		0.000231	0.000231
		(0.000145)	(0.000145)
Age	0.000132	-6.64e-05	6.60e-05
	(0.000197)	(9.97e-05)	(0.000196)
Gender	0.000639	0.00114	0.00178
	(0.00541)	(0.00236)	(0.00534)
Cassava Production Experience		7.11e-05	7.11e-05
		(8.02e-05)	(8.02e-05)
Household Size	0.00128	-0.000166	0.00112
	(0.000832)	(0.000380)	(0.000820)

Variables	(1) Direct Effect	(2) Indirect Effect	(3) Total Effect
Flood		-0.00336	-0.00336
		(0.00330)	(0.00330)
ICT	0.0137	0.00332	0.0170
	(0.0141)	(0.00387)	(0.0147)
Yield		0.00110**	0.00110**
		(0.000473)	(0.000473)
Sheep and Goat Farming	-0.000264		-0.000264
	(0.0150)		(0.0150)
Gari Production	-0.149***		-0.149***
	(0.0495)		(0.0495)
Cassava Flour Production	-0.0175		-0.0175
	(0.0113)		(0.0113)
Access to Credit	-0.00250		-0.00250
	(0.00611)		(0.00611)
Observations	1198	1198	1198

Table A4. Direct and Indirect Effects on Flood Shocks.

Variables	(1) Direct Effect	(2) Indirect Effect	(3) Total Effect
Full Harvest		0,00751	0,00751
		(0,0165)	(0,0165)
Production Cycle		-0,00128	-0,00128
		(0,00342)	(0,00342)
Starch Production		0,0694	0,0694
		(0,138)	(0,138)
Access to Electricity	0,0185	0,0957***	0,114***
	(0,0321)	(0,0313)	(0,0189)
Food Insecurity		0,0273	0,0273
		(0,0196)	(0,0196)
Farming Experience		0,000575	0,000575
		(0,000751)	(0,000751)
Age	-0,00137**	-0,000425	-0,00179**
	(0,000625)	(0,000683)	(0,000746)
Gender	0,0209	0,00591	0,0268

Variables	(1)	(2)	(3)
	(0,0171)	(0,0164)	(0,0189)
Cassava Production Experience		0,000632	0,000632
		(0,000556)	(0,000556)
Household Size	-0,0115***	-0,000338	-0,0118***
	(0,00302)	(0,00251)	(0,00335)
Drought		-0,0945	-0,0945
		(0,0696)	(0,0696)
ICT	-0,0596**	0,0218	-0,0379
	(0,0252)	(0,0241)	(0,0290)
Yield		0,00814***	0,00814***
		(0,00222)	(0,00222)
Sheep and Goat Farming	-0,0311		-0,0311
	(0,0449)		(0,0449)
Gari Production	0,204***		0,204***
	(0,0650)		(0,0650)
Cassava Flour Production	-0,0382		-0,0382
	(0,0245)		(0,0245)
Access to Credit	-0,0234		-0,0234
	(0,0177)		(0,0177)
Observations	1198	1198	1198

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