

Cassava Mosaic Disease persistence: evidence from farmer adoption patterns of management practices in Benin

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ABSTRACT

Cassava Mosaic Disease (CMD) remains a major constraint to cassava production in Sub-Saharan Africa despite extensive promotion of management practices. This study investigates the adoption and intensity of adoption of CMD management practices among 305 cassava farmers in southern Benin, using descriptive statistics and a Tobit regression model. Results show low overall adoption: only 9.84 % of farmers fully implemented all three recommended practices—use of certified disease-free cuttings, removal of infected plants, and adherence to optimal planting density. Key factors positively influencing adoption include participation in CMD-related training, disease knowledge, intercropping practices, larger farm size, and farmer age, while larger household size negatively affects adoption intensity. These findings highlight the need for integrated interventions combining farmer training, improved access to certified planting materials, intercropping promotion, and decentralized advisory services. Strengthening farmers' decision-making capacity and addressing economic constraints are critical for the sustainable management of CMD and the improvement of cassava productivity in Benin.

1. Introduction

Viral diseases affecting staple crops pose a significant threat to food security and rural livelihoods in sub-Saharan Africa (MacLeod et al., 2010; Prasanna et al., 2022; Tatineni and Hein, 2023). Among these, Cassava Mosaic Disease (CMD) is one of the most destructive, causing yield losses of up to 90 % in severe outbreaks (Thresh et al., 1994; Alicai et al., 2007; Legg et al., 2015; Rybicki, 2015). In Benin, CMD affects more than 85 % of cassava fields, often with severity levels above critical thresholds, leading to substantial yield reductions (Houngue et al., 2018,

2022). This situation is particularly alarming given that cassava (*Manihot esculenta*) is the second most widely cultivated crop after maize in Benin (DSA, 2022) and constitutes both a staple food and a major source of income for millions of rural households (Vernier et al., 2018). Consequently, CMD represents a major challenge to agricultural resilience and rural livelihoods across the tropics.

Beyond its subsistence role, cassava serves as a key driver of rural economies by providing raw materials for diverse agro-industrial products, including starch, bioplastics, bioethanol, and animal feed (Tonukari et al., 2023; Amoakon et al., 2023; Kouakou et al., 2024). Its

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ability to thrive under marginal conditions further reinforces its strategic importance in the context of climate change (Houngue et al., 2019; Yéo et al., 2025). However, the ongoing spread of CMD, facilitated by whitefly vectors (*Bemisia tabaci*) and the use of infected planting material, severely undermines cassava's sustainability (Wolfe et al., 2017; Combala et al., 2024). This underscores the need of developing and promoting management strategies.

In this regard, several CMD management practices have been recommended, notably the use of certified disease-free cuttings, the removal of infected plants, and the adherence to optimal planting densities (Legg et al., 2015; Patil et al., 2015; Chikoti et al., 2019). Despite the proven efficacy of these practices, their adoption among farmers remains limited (Andrade-Piedra et al., 2025), which has enabled CMD to persist and spread into new production areas. It is therefore essential to understand the factors that constrain adoption in order to design effective interventions.

Previous studies suggest that technology adoption is influenced by a complex interplay of socio-economic, institutional, and behavioural factors (Feder et al., 1985; Adjéi et al., 2024; Ahoya et al., 2024). The Diffusion of Innovations Theory (Rogers, 2003) and the Theory of Planned Behaviour (Ajzen, 1991) emphasize the roles of information access, perceived benefits, social influence, and institutional support in shaping farmers' behaviour. The application of these frameworks to the management of CMD can elucidate why farmers may or may not adopt recommended practices, even when their agronomic benefits are well established.

Building on these theoretical foundations, this study seeks to (i) assess the extent of adoption of CMD management practices among cassava farmers in Benin and (ii) identify the socio-economic and behavioural factors influencing adoption intensity. By generating robust empirical evidence, the study contributes to the design of targeted policies and interventions for sustainable CMD control. More broadly, it contributes to understanding the behavioural and structural levers needed to promote plant health management in resource-limited farming systems.

2. Material and methods

2.1. Description of CMD management practices

Cassava Mosaic Disease (CMD) management relies on a combination of cultural and phytosanitary practices designed to reduce the incidence and spread of cassava mosaic begomoviruses. Based on scientific evidence and national guidelines, three core strategies are recommended in Benin: (i) the use of certified disease-free planting material, (ii) regular field monitoring and removal of infected plants, and (iii) adherence to optimal planting density.

(i) Use of certified disease-free cuttings

The use of virus-free cassava cuttings is one of the most effective preventive measures against CMD. It prevents the introduction of the virus into new plots and supports healthy crop establishment (Thresh and Cooter, 2005; Chikoti et al., 2019). Studies have shown that using clean planting material can significantly increase yields compared to infected cuttings (Fargette et al., 1988; Thresh et al., 1994). The availability of certified cassava cuttings depends on efficient local multiplication systems, which in turn rely on initial virus-elimination techniques such as thermotherapy and meristem culture to produce pathogen-free plantlets (Yéo et al., 2020; Ouédraogo et al., 2025). These plantlets serve as the foundation for large-scale multiplication and distribution of healthy planting material, thereby ensuring that farmers have sustained access to clean cuttings essential for effective CMD control.

(ii) Regular field monitoring and removal of infected plants

The regular monitoring of cassava fields and prompt removal of symptomatic plants are critical to reduce viral inoculum and prevent further spread of CMD. This strategy is particularly effective when combined with the use of clean planting materials (Thresh and Cooter, 2005; Chikoti et al., 2019). Field observations in Kenya and Uganda have demonstrated that phytosanitation in susceptible varieties can result in yields comparable to those from resistant varieties (Mallowa et al., 2011). The timely removal of infected plants, especially during the early stages of growth, limits whitefly-mediated transmission (Guthrie, 1990).

(iii) Adherence to optimal planting density

Planting density influences CMD spread by affecting vector behaviour and plant-to-plant contact. Research indicates that low-density plots facilitate greater whitefly movement and virus transmission within fields (Fargette et al., 1990). Furthermore, plant located along field borders are particularly vulnerable to initial vector invasions, which often results in higher CMD incidence compared to central plants (Egabu et al., 2001). In Benin, the recommended cassava spacing is 1 m between plants and 1 m between rows, which reduces vector access, suppresses weed competition, and supports uniform crop development. Optimal spacing is thus a low-cost cultural practice that contributes to integrated CMD management.

2.2. Study area

The study was conducted in Agricultural Development Poles (PDA) 5, 6, and 7 of Benin, covering the departments of Atlantique, Couffo, Mono, Ouémé, Plateau, and Zou (Fig. 1). These regions represent the country's major cassava-producing zones, collectively accounting for over 60 % of national cassava production (DSA, 2022). The area benefits from favourable agroecological conditions, including well-drained ferruginous soils and annual rainfall between 900 and 1200 mm. However, CMD remains a major threat due to high vector pressure and widespread use of infected planting materials (Houngue et al., 2018, 2022). Given this, a field survey was conducted to generate empirical evidence on farmers' socio-economic characteristics, agricultural practices, and strategies for managing CMD.

2.3. Sampling and data collection

Primary data were collected through a structured survey of cassava farmers in the study area. A comprehensive questionnaire, digitized via KoboToolbox, was used to ensure standardized data collection. Enumerators were selected and trained on data collection. Prior to data collection, the questionnaire was pre-tested in a comparable zone outside the study area with the aim of validating the relevance of the questionnaire and the reliability of the data. The questionnaire was designed to explore various aspects, including the socio-economic characteristics of farmers, their agricultural practices, their access to production factors, and their strategies for managing CMD.

To form a representative sample, lists of cassava farmers were obtained from the Communal Cell Leaders (CCeC) of the relevant municipalities. A random sampling approach was then applied. Farmers were contacted via phone only to explain the study objective, obtain their informed consent, and invite them to the communal cell offices, where the face-to-face interviews were conducted. In total, 305 farmers participated. To overcome potential language barriers and ensure clear communication, local interpreters were mobilized when needed (Kombo et al., 2012).

2.4. Econometric model

2.4.1. Adoption index of CMD management practices

Before identifying the factors associated with the adoption and

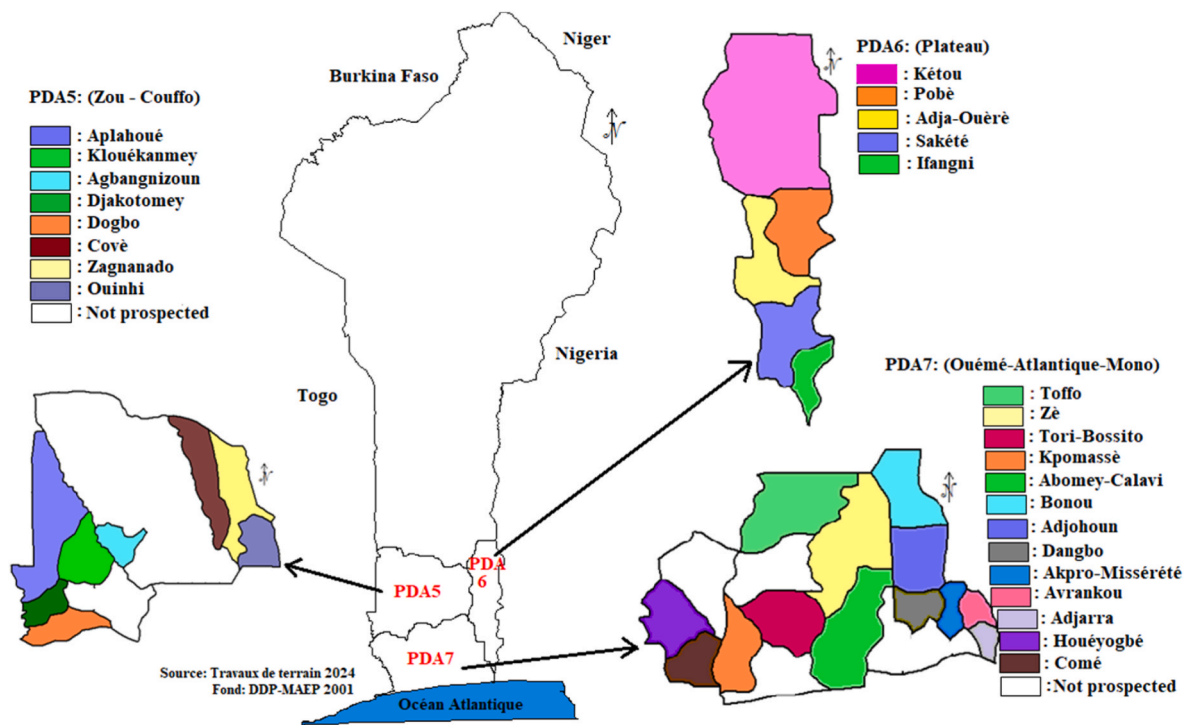


Fig. 1. Map showing the study area.

intensity of adoption of CMD management practices, it is important to determine the level of adoption of the practices by each cassava farmer. Thus, farmers who do not adopt any of the three CMD management practices are classified as non-adopters, while those who adopt at least one of them are classified as adopters.

To assess the level of adoption of CMD management practices, the adoption index proposed by Cholo et al. (2023) was used. This index allows to measure the level of adoption of each CMD management practice by farmers. The index is calculated by summing the adoption quotients of each practice and then dividing the sum by the number of recommended practices (Kassa et al., 2021; Cholo et al., 2023). The mathematical formula for the Adoption Index is as follows:

$$IA_i = \frac{\varepsilon(BS + DBI + DP)}{NPR}$$

With:

- IA_i = Adoption Index of the i th farmer;
- BS = Use of disease-free and virus-free planting material;
- DBI = cassava regular field monitoring and the removal of infected plants;
- DP = adherence to optimal planting density;
- NPR = Number of recommended practices.

The adoption index ranges from 0 (no adoption) to 1 (full adoption of all practices). Based on their scores, farmers were categorized into four adoption levels: non-adopters (0), low (0.01–0.33), medium (0.34–0.67), and high adopters (0.68–1) (Table 2).

2.4.2. Estimation of the Tobit regression model

To identify the determinants of adoption and its intensity, the Tobit model was used. This model is appropriate for simultaneously estimating the likelihood of adoption and the extent of adoption among adopters (Tafese, 2016; Kassa et al., 2021). It also enables the analysis when the dependent variable (here, the adoption index) is continuous but censored at 0 and 1.

Moreover, the Tobit model generates robust and reliable results

when applied to both discrete and continuous variables. Accordingly, numerous empirical studies have employed this model to identify the factors influencing both the adoption and the intensity of technological adoption (Gebre et al., 2022; Cholo et al., 2023).

The Tobit model, initially proposed by Tobin (1958) and further developed by Moffitt (1982) and Maddala and Lahiri (1992), is specified as follows:

$$IA_i^* = B_0 + B_i X_i + U_i$$

$$IA_i = IA_i^*, \text{ if } B_0 + B_i X_i + U_i > 0 \quad (1)$$

$$IA_i = 0, \text{ if } B_0 + B_i X_i + U_i \leq 0 \quad (2)$$

Where:

- IA_i^* = the latent variable and the solution to the utility maximization problem of adoption intensity, subject to a set of constraints per farmer and conditioned to be above a certain threshold;
- IA_i = the Adoption Index of the i th farmer;
- X_i = the vector of factors affecting adoption and adoption intensity;
- B_i = the vector of unknown parameters; and
- U_i = the error term, which is normally distributed with a mean of 0 and a variance of σ^2 .

2.4.3. Explanatory variable of the econometric model

The selection of explanatory variables was informed by the theoretical and empirical literature on the adoption and intensity of adoption of agricultural innovations. The adoption of CMD management practices is influenced by a multitude of socio-economic, institutional, and agro-ecological factors, whose relevance varies with context (Feder et al., 1985; Rogers, 2003).

The explanatory variables selected in this study are as follows:

- **Farmer's Age (AGE):** A continuous variable representing the respondent's age in years. While experience may enhance adoption capacity, older farmers are often less inclined to adopt innovations,

potentially due to entrenched habits or risk aversion (Mwaura et al., 2021).

- **Gender (GEN):** A binary variable (0 = female; 1 = male). Gender disparities in access to agricultural resources, credit, and extension services can significantly shape adoption behaviours (Ahoya et al., 2024).
- **Education Level (EDUCLEV):** A categorical variable with four levels: (i) illiterate, (ii) primary, (iii) secondary, and (iv) tertiary education. Higher education levels are generally associated with enhanced cognitive abilities and greater responsiveness to new technologies (Abiola et al., 2020; Amon-Armah et al., 2021).
- **Marital Status (MATRISTAT):** A categorical variable with three categories: (i) single, (ii) married, and (iii) divorced. Married individuals may benefit from household labour and social capital, facilitating innovations uptake (Nahayo et al., 2017).
- **Household size (HOUSESIZE):** A continuous variable measuring the total number of individuals living in the household under the authority of the household head. Given the high labour requirements associated with certain CMD management practices, particularly the removal and destruction of infected plants, it is hypothesized that larger households, with greater availability of family labour, are more likely to adopt these practices (Jogo et al., 2013).
- **Distance Between the Field and the Residence (DISTHCASS):** A continuous variable (in kilometers). Greater distance between the field and the residence may pose logistical constraints to frequent monitoring and application of management practices (Yabi et al., 2016).
- **Cassava Production Area (CASSPROREA):** Measured in hectares, this continuous variable serves as a proxy for farm size. Larger holdings are often associated with higher levels of technology adoption due to economies of scale (Midamba et al., 2024).
- **Intercropping Practice (INTERPRACT):** A binary variable (0 = no; 1 = yes). Intercropping may influence pest and disease dynamics and foster the integration of CMD control strategies (Ahoya et al., 2024).
- **Farmers' Knowledge Level on CMD (KNOWCMD):** An index variable derived from farmers' responses to five knowledge questions covering CMD symptoms, disease name, causative agents, transmission mechanisms, and control practices. This variable reflects the farmer's cognitive capacity to identify and manage CMD risks (Adjéi et al., 2024; Ahoya et al., 2025).
- **Participation in Training and Awareness Programs on CMD (PATIFORM):** A binary variable (0 = no; 1 = yes). Participation enhances access to timely and accurate information, positively influencing adoption decisions (Kouassi et al., 2023; Ahoya et al., 2025).

2.4.4. Multicollinearity test

Multicollinearity refers to the presence of high correlations among two or more explanatory variables, which can inflate the standard errors of estimated coefficients, reduce statistical power, and compromise the interpretability of regression results (Wooldridge, 2016). To assess the extent of multicollinearity in the model, the Variance Inflation Factor (VIF) was used. A VIF threshold of less than 2.5 was adopted as the acceptance criterion, as it indicates a low degree of multicollinearity, thereby enhancing the reliability of coefficient estimates and preserving the explanatory power of the regression model (Kouassi et al., 2023). When variables exhibited a VIF above this threshold, auxiliary regression tests and correlation analyses were conducted to identify and address multicollinearity issues by removing or combining highly correlated variables (Daoud, 2017; Foucart, 2006).

2.4.5. Statistical analyses

All statistical analyses, including descriptive statistics, model estimation, and robustness tests, were conducted using STATA 17. This software is particularly suited for advanced econometric analyses and allows for various diagnostic tests, including residual normality tests,

heteroscedasticity tests, and autocorrelation tests, thereby ensuring the reliability of the obtained results (Cameron and Trivedi, 2010).

3. Results

3.1. Adoption of CMD management practices

The analysis revealed varying levels of adoption across the three recommended CMD management practices. While 53.77 % of farmers reported removing infected plants, and 51.48 % complied with recommended planting densities, only 28.52 % adopted the use of certified disease-free cuttings (Table 1). These results suggest a gap between farmers' awareness and the adoption of the most effective, though cost-intensive, practices.

3.2. Intensity of adoption of CMD management practices

Based on the adoption index, farmers were classified into four categories. Approximately 19.02 % did not adopt any of the practices, while 38.03 % were low adopters (index ≤ 0.33), 33.11 % were medium adopters (index between 0.34 and 0.67), and only 9.84 % were high adopters (index > 0.67) (Table 2). These results indicate that partial adoption is more common than full adoption, suggesting fragmented implementation of control strategies.

3.3. Farmer characteristics by adoption level

Descriptive statistics showed significant differences in some socio-economic and farm-related characteristics across adoption levels of adoption of CMD management practices (Table 3). High-level adopters were generally more experienced in cassava production, with a majority having more than 11 years of farming experience, compared to only 44.8 % among non-adopters. Similarly, they cultivated larger areas under cassava (4.7 ha) than their non-adopting counterparts (1.94 ha), underscoring the influence of farm size on the capacity to implement and scale management practices.

CMD knowledge scores increased progressively with the intensity of adoption, from a mean score of 3.12 among non-adopters to 6.9 among high-level adopters, highlighting the critical role of awareness and understanding in the adoption process. Furthermore, membership in a cassava farmers' association was significantly more common among medium (76.2 %) and high adopters (73.3 %) than among non-adopters (43.1 %), suggesting that social capital and access to collective learning platforms may facilitate the diffusion of innovation.

In contrast, household size exhibited a significant but negative association with adoption levels. Other variables such as gender, marital status, education level, age, mobile phone ownership, and distance from the field to the household were not statistically significant, although minor variations were observed.

3.4. Factors determining the adoption and intensity of adoption of CDM management practices

The Tobit regression results (Table 4) highlight several statistically significant factors influencing the intensity of adoption of CMD management practices. Among these, participation in CMD-related training and awareness programs (PATIFORM) emerged as the most influential

Table 1
Adoption levels of recommended CMD management practices by farmers.

Recommended management practices	Percentage	
	Adoption	Non-Adoption
Use of healthy cuttings	28.52	71.48
Removal of infected cuttings	53.77	46.23
Adherence to planting density	51.48	48.52

Table 2

Intensity of adoption of CMD management practices.

Adoption category	Adoption index score range	% of farmers
Non-Adoption	0	19.02
Low Adoption	$0 < x \leq 0.33$	38.03
Medium Adoption	$0.33 < x \leq 0.67$	33.11
High Adoption	$0.67 < x \leq 1$	9.84

determinant, demonstrating a robust positive effect. Specifically, participation in such programs increased the expected adoption index by approximately 15.9 percentage points (Table 5).

Similarly, knowledge of CMD (KNOWCMD) significantly promoted adoption: for each additional point in the knowledge score, the probability of adoption increased by 5.2 percentage points. Cassava farm size (CASSPROREA) also displayed a positive and significant effect, where each additional hectare of cassava cultivated was associated with a 1.2 percentage point increase in the adoption index. Moreover, farmers practicing intercropping (INTERPRACT) demonstrated a 13.5 percentage point higher adoption intensity compared to those practicing monoculture.

In addition, farmer age (AGE) had a statistically significant but modest positive effect, suggesting that older farmers were more likely to adopt CMD management practices. Conversely, household size (HOUSESIZE) negatively affected adoption: each additional household member reduced the expected adoption index by 1.4 percentage points. In contrast, other socio-demographic variables—including gender, marital status, educational level, and distance between cassava fields and the homestead—were not statistically significant, indicating a limited role in influencing adoption decisions.

The overall model diagnostics indicate good explanatory power, with a Pseudo R^2 of 0.429 and a highly significant model fit ($\chi^2 = 139.532$; $p < 0.001$), suggesting that the model explains a substantial portion of the variability in the intensity of CMD management practices adoption among cassava farmers.

Table 3

Descriptive statistics of farmers' characteristics by level of adoption.

Qualitative variables	Modalities	Percentage					p-value
		Total Sample (n = 305)	Non-adoption (n = 58)	Low adoption (n = 116)	Medium adoption (n = 101)	High adoption (n = 30)	chi2
Gender	Male	82.95	75.86	87.93	81.19	83.33	0.229
	Female	17.05	24.14	12.07	18.81	16.67	
Marital status	Single	3.28	0	5.17	2.97	3.33	0.387
	Married	95.74	98.28	93.97	97.03	93.34	
	Widowed	0.98	1.72	0.86	0	3.33	
Education Level	No education	33.11	41.38	29.31	36.64	20	0.637
	Primary	20	18.97	18.97	18.81	30	
	Secondary	34.75	27.59	38.79	33.66	36.67	
	Higher	12.14	12.06	12.93	10.89	13.33	
Years of experience in cassava production	1–5 years	13.77	18.97	15.52	10.89	6.67	0.023**
	6–10 years	23.61	36.2	24.14	15.84	23.33	
	More than 11 years	62.62	44.82	60.34	73.27	70	
Owns an android mobile phone	Yes	73.11	65.52	78.45	72.28	70	0.312
	No	26.89	34.48	21.55	27.78	30	
Member of a cassava farmers' Association	Yes	60.66	43.1	52.59	76.24	73.33	0.000***
	No	39.34	56.9	47.41	23.76	26.67	
Quantitative Variables		Mean (Standard Deviation)					Anova
General knowledge of CMD (Score)		5.09 (2.6)	3.12 (1.24)	4.73 (2.59)	6.1 (2.59)	6.9 (1.77)	0.000***
Age of respondent (Years)		44.92 (11.77)	42.69 (11.35)	44.73 (11.80)	45.39 (11.83)	48.7 (11.73)	0.986
Household size		8.25 (4.85)	9.32 (5.3)	8.03 (4.48)	7.77 (4.05)	8.7 (7.19)	0.000***
Area of cassava production (Ha)		2.63 (3.95)	1.94 (2.1)	2.03 (1.5)	3.09 (5.66)	4.7 (5.32)	0.000***
Distance from field to home (Km)		7.25 (6.11)	7.33 (5.51)	7.69 (7.18)	6.59 (5.08)	7.63 (5.95)	0.003***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4. Discussion

4.1. Low adoption of certified cassava cuttings: a barrier to sustainable CMD management

This study highlights a critical gap in the adoption of healthy cassava cuttings, which are essential for the effective management of Cassava Mosaic Disease (CMD). The persistently low adoption rate of certified cuttings can largely be attributed to their high cost (ranging from USD 175 to 215 per hectare) and their limited availability, particularly in rural areas. As noted by Buddhakulsomsiri et al. (2015), smallholder farmers often face financial constraints that prevent them from investing in certified planting material. In addition, long-standing farmer expectation of “free” seed distribution further diminishes the willingness to purchase certified cuttings. These observations align with findings by Combala et al. (2024), who demonstrated that the widespread use of self-propagated, low-cost cuttings significantly contributes to the continued spread of CMD. Furthermore, the absence of efficient and accessible distribution networks exacerbates the challenge, as noted by Eni et al. (2021), who reported that even farmers willing to buy certified materials face difficulties in obtaining them. Therefore, it is imperative to implement a more integrated seed distribution system, accompanied by policy measures aimed at government subsidizing certified cuttings, in order to overcome these financial and logistical barriers.

4.2. The role of training and knowledge dissemination in enhancing adoption

Training programs have proven to be a pivotal mechanism for increasing farmers knowledge of CMD and fostering the adoption of management practices. Our results indicate that participation in training significantly improves both the likelihood and intensity of adoption. These findings align with previous studies (Yang et al., 2008; Abiola et al., 2020; Tambo et al., 2021) which highlight the critical role of training-based knowledge dissemination in driving behavioural change

Table 4

Tobit model estimation for factors influencing the adoption and intensity of adoption of CMD management practices.

Independent Variable	Coef. ^a	St.Err. ^b	t-value	p-value	[95 % Conf	Interval]	Sig
PATIFORM	0.159	0.04	4.00	0.000	0.08	0.237	***
KNOWCMD	0.052	0.007	7.33	0.000	0.038	0.065	***
GEN	0	–	–	–	–	–	
Female	0.007	0.049	0.13	0.895	–0.091	0.104	
AGE	0.004	0.002	2.32	0.021	0.001	0.008	**
MATRISTAT	0	–	–	–	–	–	
Married	–0.146	0.096	–1.51	0.132	–0.336	0.044	
Widowed	–0.082	0.2	–0.41	0.681	–0.475	0.311	
HOUSESIZE	–0.014	0.004	–3.57	0.000	–0.022	–0.006	***
ACT_PRIPAL	0.086	0.057	1.50	0.135	–0.027	0.198	
CASSPROREA	0.012	0.004	2.62	0.009	0.003	0.02	***
INTERPRACT	0.135	0.035	3.82	0.000	0.066	0.205	***
EXPCASS	0.039	0.028	1.41	0.158	–0.015	0.094	
EDUCLEVEL	0	–	–	–	–	–	
Primary	–0.025	0.049	–0.50	0.616	–0.121	0.072	
Secondary	0.011	0.045	0.25	0.8	–0.078	0.101	
Higher	–0.043	0.064	–0.67	0.505	–0.17	0.084	
DISTHCASS	–0.004	0.003	–1.29	0.197	–0.009	0.002	
Constant	–0.08	0.133	–0.60	0.548	–0.341	0.182	
Var	0.079	0.007	–	–	0.066	0.095	
Mean dependent var	0.446		SD dependent var			0.299	
Pseudo r-squared	0.429		Number of obs			305	
Chi-square	139.532		Prob > chi2			0.000	
Akaike crit. (AIC)	219.924		Bayesian crit. (BIC)			283.169	

***p < 0.01, **p < 0.05, *p < 0.1.

^a coefficient.^b Standard Error.**Table 5**

Marginal effects (dy/dx) from the Tobit regression for factors influencing the adoption and intensity of adoption of CMD management practices.

	dy/dx	std. ^c	err. ^d	T ^e	P > t ^f	[95 %
PATIFORM	0.159	0.040	4.000	0.000	0.080	0.0237
KNOWCMD	0.052	0.007	7.330	0.000	0.038	0.065
AGE	0.004	0.002	2.320	0.021	0.001	0.008
HOUSESIZE	–0.014	0.004	–3570	0.000	–0.022	–0.006
CASSPROREA	0.012	0.004	2.620	0.009	0.003	0.020
INTERPRACT	0.135	0.035	3.820	0.000	0.066	0.205

cStandard deviation.

dStandard error.

e-t-value.

fp-value.

and technology adoption among farmers. Our findings further suggest that when farmers clearly perceive the long-term advantages of improved practices—such as increased productivity and effective disease management—they are more likely to allocate scarce resources to certified planting material.

However, knowledge acquisition alone is insufficient to drive sustained behavioural change in the absence of appropriate socio-economic incentives. As highlighted by Murray-Watson et al. (2022), training initiatives must be coupled with complementary financial mechanisms, such as subsidies or credit schemes, to mitigate the initial economic barriers faced by farmers. Without such integrated support structures, the transformative potential of knowledge dissemination efforts is likely to remain limited.

4.3. Behavioural and socioeconomic constraints: the complexity of CMD management

A comprehensive understanding of the barriers to the adoption of cassava mosaic disease (CMD) management practices requires closer examination of the socioeconomic determinants influencing farmers' decision-making processes. Our analysis reveals that household size negatively correlates with the adoption of CMD management practices,

likely due to increased financial pressures in larger households. This financial strain often forces farmers to prioritize immediate livelihood needs over long-term investments in disease management. This finding aligns with the budget constraint theory posited by Feder (1985), underscoring the necessity for interventions that simultaneously address financial limitations and behavioural dynamics among smallholder farmers.

Additionally, the age of the household head significantly influences on adoption behaviour. Although older farmers possess extensive agricultural experience, they may demonstrate a reluctance to embrace new technologies, favouring traditional practices instead. This generational conservatism, as noted by Asfaw et al. (2012), underscores the importance of designing extension services that are sensitive to generational differences. Such services should foster innovation among younger farmers while leveraging the valuable experiential knowledge of older farmers, thereby promoting a more holistic and sustainable approach to CMD management.

4.4. Innovative solutions: integrating ecological and technological approaches

The findings of this study demonstrate that the adoption of CMD management practices remains constrained by limited access to certified cuttings, incomplete implementation of intercropping, and substantial gaps in farmer knowledge and training. Addressing the persistent challenge of CMD requires the development of integrated strategies that simultaneously account for farmers' economic constraints, strengthening ecological resilience, and leverage technological innovations.

Agroecological practices represent a critical component of such strategies. The present analysis has confirmed intercropping as a significant positive determinant of adoption intensity. This practice has been shown to both mitigate CMD incidence and enhance soil fertility and overall cropping systems resilience (Bellotti and Arias, 2001). It is recommended that complementary measures be implemented, including improved management of cassava-whitefly (Bayiyana et al., 2025). This will serve to further strengthen system resilience and directly target vector-mediated disease transmission. The latter of which remains a primary challenge in affected regions.

At the same time, the findings underscore the pivotal role of training and knowledge dissemination. Digital agriculture innovations offer substantial potential to overcome these knowledge barriers. Tools such as PlantVillage Nuru, which integrate machine learning with participatory farmer engagement, facilitate rapid field-level CMD detection and real-time dissemination of management recommendations (Mrisho et al., 2020). The integration of such technologies can significantly enhance farmers' decision-making capacities and reduce information asymmetries that hinder timely response to disease outbreaks.

However, for these innovations to yield meaningful and sustained impact, their adoption must be embedded within an enabling policy and institutional environment. This includes inclusive extension systems sensitive to gender and generational differences, targeted subsidies for certified disease-free planting materials to alleviate cost constraints, and investments in rural connectivity to enable digital tool utilization. Moreover, policy frameworks should promote hybrid approaches that integrate local knowledge systems with scientifically validated practices. By fostering synergies between traditional agroecological methods and modern technologies, stakeholders can co-develop adaptive and resilient CMD management strategies tailored to local contexts.

5. Conclusion and policy implications

The persistence of Cassava Mosaic Disease (CMD) in Benin highlights critical failures in translating agronomic knowledge into effective on-farm practices. Despite decades of research and extension efforts, the adoption of recommended CMD control strategies remains low and fragmented. Only 9.84 % of farmers fully adopted all three core practices, while 19.02 % did not adopt any. Key drivers of adoption include participation in training programs, disease knowledge, intercropping practices, age, and farm size, whereas larger household size acts as a barrier.

To address these challenges, policy actions must go beyond information dissemination. They should simultaneously tackle economic and structural bottlenecks by:

- Scaling up participatory training and experiential learning platforms;
- Subsidizing certified disease-free cuttings through instruments such as government subsidies, voucher schemes, or donor-supported cost-sharing programs, in order to reduce the financial burden on small-holder farmers and stimulate wider adoption;
- Strengthening decentralized seed systems by supporting community-based certified multipliers with training, certification, and provision of starter stock, thereby improving the availability and accessibility of healthy planting material in rural areas;
- Promoting intercropping within broader Integrated Disease Management (IDM) frameworks;
- Tailoring interventions to account for household demographic pressures;
- Enhancing decentralized advisory services through community-based models and digital tools;
- Developing sustainable whitefly control strategies integrated with CMD management;
- Strengthening regional coordination for harmonized seed certification and disease surveillance is critical, since CMD is spread not only by whitefly vectors but, more importantly, through the farmer-to-farmer exchange and cross-border movement of infected cassava cuttings. Coordinated efforts can ensure that only virus-free planting materials circulate across local and national borders, while joint surveillance systems enable early detection and rapid response to outbreaks.

Ultimately, building CMD-resilient cassava systems requires an integrated strategy that empowers farmers, reduces their economic risks, and embeds sustainable plant health practices within local agricultural development pathways. Future research should explore the scalability

and cost-effectiveness of integrated intervention packages across diverse agro-ecological contexts.

CRedit authorship contribution statement

Déwanou Kant David Ahoya: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing. **Ettien Antoine Adjéi:** Formal analysis, Writing – original draft, Writing – review & editing. **Serge Sètonji Houedjissin:** Investigation, Writing – review & editing. **Jérôme Anani Houngue:** Investigation, Writing – review & editing. **Martine Zandjanakou-Tachin:** Supervision, Writing – review & editing. **Jacob Afouda Yabi:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing. **Eveline Marie Fulbert Windinmi Sawadogo-Compaore:** Supervision, Writing – review & editing. **Modeste Kan Kouassi:** Project administration, Writing – review & editing. **Fidèle Tiendrébéogo:** Project administration, Writing – review & editing. **Ousmane Ndoeye:** Funding acquisition, Project administration, Writing – review & editing. **Justin Simon Pita:** Project administration, Resources, Supervision. **Corneille Ahanhanzo:** Project administration, Resources, Supervision.

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Declaration of competing 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.

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Data availability

Data will be made available on request.

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