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ROLE OF HUMAN CAPITAL IN ADOPTION OF VIRUS-RESISTANT CASSAVA VARIETIES IN TSHOPO PROVINCE, DEMOCRATIC REPUBLIC OF THE CONGO

RÔLE DU CAPITAL HUMAIN DANS L'ADOPTION DES VARIÉTÉS DE MANIOC RÉSISTANTES AUX VIRUS DANS LA PROVINCE DE TSHOPO, RÉPUBLIQUE DÉMOCRATIQUE DU CONGO

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ABSTRACT

Cassava (*Manihot esculenta* Crantz, 1766) is a key staple crop for food security in sub-Saharan Africa (SSA), yet its production is severely constrained by viral diseases such as Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD). The dissemination of resistant varieties, therefore, represents a crucial technological response for smallholder farmers. This study analysed the determinants of the adoption of virus-resistant cassava varieties among smallholder farmers in Tshopo Province in the DRC, with particular focus on the role of human capital. The analysis used data from 500 farming households collected through a multi-stage sampling approach and applied descriptive statistics, Chi-square tests, and a binary logit model to examine adoption determinants. Results revealed that 67% of the cassava farmers used at least one resistant variety, with 55.6% combining local and resistant types; a pattern reflecting partial and incremental adoption. Econometric analysis highlighted human capital as the primary driver of adoption; namely, technical training, education level, farming experience, and household size; all of which significantly increased adoption likelihood. In contrast, productive resources and passive information access showed no significant effect on the adoption. These findings suggest that the adoption of resistant varieties is embedded in a learning process under conditions of imperfect information, with individual producer capacities playing a decisive role in the gradual integration of innovations.

Key Words: Cassava viral disease, *Manihot esculenta*

RÉSUMÉ

Le manioc (*Manihot esculenta* Crantz, 1766) constitue une culture vivrière clé pour la sécurité alimentaire en Afrique subsaharienne (ASS), mais sa production est fortement contrainte par des maladies virales telles que la mosaïque du manioc (Cassava Mosaic Disease, CMD) et la striure brune du manioc (Cassava Brown Streak Disease, CBSD). Dans ce contexte, la diffusion de variétés résistantes représente une réponse technologique cruciale pour les petits exploitants agricoles. Cette étude a analysé les déterminants de l'adoption des variétés de manioc résistantes aux maladies virales chez les petits producteurs de la Province de la Tshopo (RDC), en mettant un accent particulier sur le rôle du capital humain. L'analyse a utilisé des données collectées auprès de 500 ménages agricoles à travers un échantillonnage stratifié et a mobilisé des statistiques descriptives, des tests du Khi-deux et un modèle logit binaire. Les résultats révèlent que 67 % des producteurs utilisaient au moins une variété résistante, 55,6 % combinant des variétés locales et résistantes, ce qui reflète une adoption partielle et progressive. L'analyse économétrique a mis en évidence que le capital humain est le principal moteur de l'adoption: la formation technique, le niveau d'éducation, l'expérience agricole et la taille du ménage augmentent tous significativement la probabilité d'adoption. En revanche, les ressources productives et l'accès passif à l'information n'ont montré aucun effet significatif sur l'adoption. Ces résultats suggèrent que l'adoption des variétés résistantes s'inscrit dans un processus d'apprentissage en contexte d'information imparfaite, où les capacités individuelles des producteurs jouent un rôle déterminant dans l'intégration progressive des innovations.

Mots Clés: Maladie virale du manioc, *Manihot esculenta*

INTRODUCTION

In the smallholder-dominated agricultural systems in sub-Saharan Africa (SSA), the adoption of technological innovations is a key lever for improving agricultural productivity and enhancing food security for rural households. In the SSA region, cassava (*Manihot esculenta* Crantz, 1766) plays a central role in the food systems and livelihoods of rural populations (Nweke *et al.*, 2002; Nassar and Ortiz, 2010). However, its production remains severely constrained by viral diseases, notably Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD), which cause substantial yield losses and threaten rural household food security (Legg *et al*., 2006; Patil *et al*., 2018; Legg *et al*., 2020). In this context, dissemination of resistant varieties represents one of the most sustainable options for stabilising production, particularly in smallholder-dominated systems. Despite progress in the development of these technologies, their effective diffusion often remains limited across many regions of SSA. This persistent gap between the availability of innovations and their adoption by farmers, represents a major issue in the agricultural economics literature (Doss, 2006; Foster and Rosenzweig, 2010).

In the DRC, research institutions and agricultural extension services have promoted these varieties for over two decades as the primary strategy for managing viral diseases (Wossen *et al*., 2017; Mahungu *et al*., 2022). However, their adoption remains low and heterogeneous across regions and among farmers. This is particularly due to constraints in accessing improved planting materials, limited technical information, and persistent preferences for certain local varieties, often better suited to culinary and commercial uses; but more susceptible to diseases (Mahungu *et al*., 2022).

This heterogeneity demonstrates that the mere availability of an innovation does not necessarily result in its successful adoption. In contexts characterised by information constraints, imperfect markets, and varying learning capacities; adoption decisions result

from complex interactions between socio-economic, institutional, and cognitive factors (Feder *et al*., 1985; Doss, 2006). In this regard, literature highlights the determining role of human capital, access to information, and extension services in learning processes (Bandiera and Rasul, 2006; Conley and Udry, 2010; Foster and Rosenzweig, 2010). Farmers with higher education levels, greater farming experience, or better access to technical training are generally better equipped to assess the benefits of innovations and integrate them into production systems (Schultz, 1964).

Despite these advances, empirical knowledge regarding the determinants of adoption of resistant cassava varieties remains insufficiently documented in certain specific contexts, particularly in isolated agricultural areas such as Tshopo Province in the DRC. This region is characterised by relative market isolation, limited access to improved inputs and extension services, as well as a strong dependence of agricultural households on cassava cultivation (Omasombo *et al*., 2020). In such a context, learning mechanisms, particularly those related to human capital, may play a decisive role in the diffusion of innovations.

Against this backdrop, the present study examined the determinants of the adoption of cassava varieties resistant to viral diseases among smallholder farmers in Tshopo Province in the DRC. More specifically, it aims to highlight the role of human capital in this process by showing how farmers' learning capacities influence the gradual integration of these varieties into production systems.

METHODOLOGY

Study area. The study was conducted in Tshopo Province (0° 312 N, 25° 122 E), in the northeastern part of the DRC. As one of the country's primary cassava production basins, this province is characterised by a high dependence of rural households on cassava for both food security and livelihoods (FAO, 2013; Mahungu *et al*., 2022).

The province features a hot, humid equatorial climate, with abundant rainfall (mean annual = 1724 mm) and relatively stable temperatures (mean annual = 25.3°C) throughout the year (Balandi *et al*., 2025). These agroecological conditions favour the production of food crops, particularly cassava, but are also conducive to the development of viral diseases affecting this crop (Legg *et al*., 2006; 2020).

Agricultural production systems in the region are dominated by small-scale farms practising diversified subsistence farming, in which cassava is the main crop and is frequently intercropped with other crops such as maize or groundnuts (Omasombo *et al*., 2020). This organisation of production systems reflects risk management strategies in the context of uncertainty, particularly due to phytosanitary constraints and limited access to improved inputs (Ellis, 2000; Frelat *et al*., 2016).

Given the economic importance of cassava, the persistent threat of viral diseases, and the structural constraints on access to information and agricultural innovations, Tshopo Province offers a relevant case study for analysing the determinants of resistant cassava variety adoption.

Data collection. Data were collected through field surveys, using a semi-structured questionnaire. The questionnaire was pre-tested to improve its clarity, coherence, and sequencing of the questions, as well as to ensure consistency in enumerator interpretation of the instrument. The questionnaire was administered orally to household heads *via* the KoboCollect application.

Interviews were conducted in local languages (Lingala and Swahili) to minimise language-related biases. Enumerators were trained on the content of the questionnaire and data collection procedures to ensure consistency and reliability of the information collected.

The data collected included farmers' socio-demographic characteristics, structural characteristics of their farms, cassava production practices, use of local and resistant varieties, access to information, training, and extension services.

Particular attention was given to human capital variables. Education level was operationalised as an ordinal variable corresponding to the highest level of formal education completed (no formal education, primary, secondary, higher education). Experience in cassava cultivation was measured in years. Technical training in cassava production was captured as a binary variable (1 = farmer having received training; 0 = otherwise). Household size was measured by the total number of individuals living in the household at the time of the survey.

Sampling strategy. The study was based on a sample of 500 cassava-producing households. The sample size was determined following Cochran (1977), commonly used in socio-economic and agricultural surveys. At a 95% confidence level (Z = 1.96), a 5% margin of error (e = 0.05), and maximum variability (P = 0.5), the minimum required sample size was 384 households. This was increased to 500 to account for potential non-response and sampling variability.

A multi-stage sampling approach was adopted. In the first stage, the territories of Tshopo Province were treated as stratification units to account for the heterogeneity of agricultural production systems. The sample size was then allocated across territories in proportion to their agricultural significance, as estimated from the 2022 agricultural survey of the Provincial Inspectorate of Agriculture and Food Security of Tshopo, including the hinterland of Kisangani. In the second stage, villages and farming households were selected based on village accessibility, the importance of cassava production and the diversity of farming practices.

Model specification and variable definition. The analysis of the determinants of the adoption of resistant cassava varieties was conducted using a binary logit model, which was appropriate for the dichotomous nature of the dependent variable (Wooldridge, 2010; Greene, 2012). The model estimated the probability that a farmer adopts at least one resistant variety based on individual characteristics, farm resources, and access to information.

The dependent variable (adoption status) represented the adoption of resistant cassava varieties. It was constructed as a binary variable, taking the value 1 if the farmer reported using at least one resistant variety, and 0 otherwise. The identification of resistant varieties was based on farmers' declarations, supported by their recognition of varieties from dissemination programmes. In smallholder systems, farmers distinguish varieties based on their origin and agronomic performance. While farmers may not always know the scientific names of these varieties, they rely on observable traits such as disease tolerance and yield to identify them. The frequent coexistence of local and resistant varieties within the same farm further facilitates this differentiation.

During the survey, farmers were asked about the origin of the cuttings used (diffusion programmes, extension services, or farmer-to-farmer exchanges) and the perceived agronomic characteristics of the varieties, particularly disease tolerance and yield performance, to minimise classification errors. This approach captured adoption as an effective behaviour under real farming conditions (Feder *et al*., 1985).

Explanatory variables were selected from field-collected data and organised into three groups, consistent with the literature on agricultural technology adoption (Doss, 2006; Anderson and Feder, 2007; Wossen *et al.*, 2017). The first group comprised human capital variables, including educational level (an

ordinal variable measuring the highest level of education achieved within the household), experience in cassava cultivation (years), technical training in cassava production (binary variable), and household size (number of individuals). Household size served as an indicator of organisational capacity and labour availability. The second group included farm socio-economic and productive characteristics, notably cassava cultivated area (in hectares) and farmer age (in years). The third group related to access to information and services, including access to agricultural extension services and to media sources (radio, television, and internet), measured as binary variables.

All these variables were incorporated into the model to analyse their respective contributions to adoption probability, with particular emphasis on human capital. Table 1 summarises the definitions, coding, and expected theoretical sign of the variables included in the model.

Data analysis. The empirical analysis was structured in three complementary steps. Firstly, descriptive statistics were used to characterise the farmers and assess the level of adoption of resistant cassava varieties in the study area. Secondly, a bivariate analysis based on the Chi-square (χ^2) test was conducted to examine the statistical relationships between farmers' characteristics and their adoption status. The strength of these relationships was assessed using Cramer's V coefficient. To interpret the intensity of the associations, a classification framework consistent with common practices in the social sciences was adopted. Values below 0.10 were considered very weak, those between 0.10 and 0.20 weak, those between 0.20 and 0.40 moderate, and those above 0.40 strong (Cohen, 1988; De Vaus, 2002). In the third step, a binary logistic regression (logit model) was estimated to identify the factors associated with the probability of adopting resistant varieties, controlling for other explanatory variables (Feder *et al*., 1985; Greene, 2012). The model was specified as follows:

$$\ln(P/(1-P)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k \quad \text{Equation 1}$$

Where:

P = the probability of adoption; X = set of explanatory variables; and the estimated coefficients are interpreted in terms of odds ratios (e^βk).

The overall validity of the model was assessed using the likelihood ratio test; while its goodness-of-fit was evaluated using McFadden's Pseudo Coefficient of Determination, in line with standard practice (Wooldridge, 2010; Greene, 2012). Potential multicollinearity among the explanatory variables was examined using the Variance Inflation Factor (VIF) (Gujarati and Porter, 2009). All statistical tests were interpreted at the 5% significance level.

Ethical considerations. All participants provided oral informed consent prior to data collection. The purpose of the study, its voluntary nature, and the right to withdraw at any time were clearly explained to all participants. No personally identifiable information was collected, and all data were securely stored and used for research purposes.

RESULTS

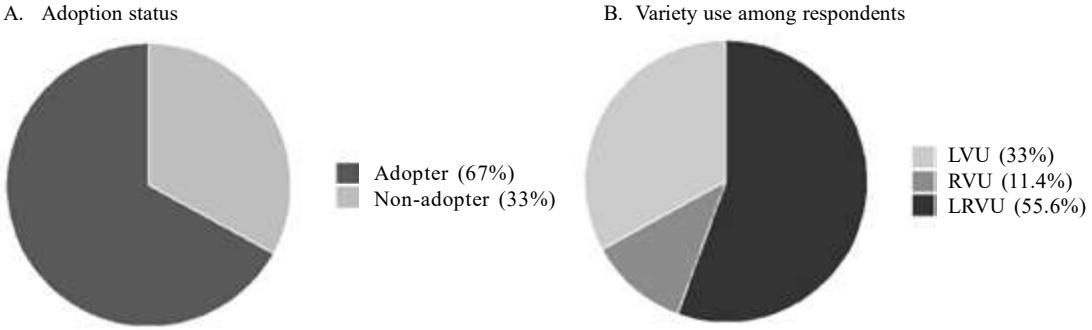
Adoption of cassava varieties resistant to viral diseases Figure 1 presents the distribution of farmers according to their adoption status and types of varieties cultivated.

The results indicate that 67% of farmers used at least one resistant variety; while 33% cultivated exclusively local varieties. Among the adopters, 11.4% used only resistant varieties; whereas 55.6% combined local and

TABLE 1. Definition and coding of the variables used in the adoption model of virus-resistant cassava varieties among smallholder farmers in Tshopo Province, Democratic Republic of the Congo

Variables	Description	Measurement / coding	Type	Expected sign
Adoption (Y)	Use of at least one resistant variety of cassava	1 = adopter; 0 = non-adopter	Binary	-
EL	Farmer's education level	Level of education (in ascending order)	Ordinal	+
HS	Household size	Total number of household members	Quantitative	+
FE	Farming experience in cassava cultivation	Number of years of practice	Quantitative	+
TCP	Training in cassava production	1 = trained; 0 = not trained	Binary	+
AES	Access to extension services	1 = has access to agricultural extension services; 0 = no	Binary	+
CA	Area under cassava cultivation	Area in hectares	Quantitative	+
Age	Age of the farmer	Age in years	Quantitative	±
AR	Access to radio	1 = yes; 0 = no	Binary	+
AT	Access to television	1 = yes; 0 = no	Binary	+
AI	Access to the internet	1 = yes; 0 = no	Binary	+
PAP	Perceived agricultural performance	Ordinal perception scale	Ordinal	±

Note: the expected sign indicates the theoretical effect of each variable on the probability of adopting resistant varieties



LVU = Local variety users; RVU = Resistant variety users; LRVU = Users of both local and resistant varieities

Figure 1. Adoption status of virus-resistant varieties and variety usage profiles among cassava farmers in the Tshopo Province, Democratic Republic of Congo.

resistant types. This pattern reflects a predominantly partial and gradual adoption process, characterised by the coexistence of traditional and introduced planting materials within the same farming systems.

Determinants of adoption of resistant cassava varieties. Table 2 presents the results of the Chi-square (χ^2) tests examining the bivariate relationships between selected farmer characteristics and adoption status of resistant cassava varieties.

Human capital determinants. Education level was significantly associated with adoption status ($\chi^2 = 11.319$; $P = 0.0232$), with a moderate effect size (Cramer's $V = 0.277$). Farmers with secondary education represented the largest proportion among adopters (37.2%), followed by those with primary education (24.2%). Cassava farming experience did not show a significant association with adoption status in the bivariate analysis, although farmers with more than 11 years experience constituted many adopters. Table 3 presents the results of the logit model estimating the probability of adopting resistant varieties based on farmers' characteristics, farm attributes, and their access to information.

Training in cassava production emerged as the most influential determinant of adoption, with a positive and highly significant effect ($P < 0.01$; OR = 3.595). Farmers who received technical training were approximately 3.6 times more likely to adopt resistant varieties than untrained farmers. Farming experience also positively influenced adoption ($P < 0.01$; OR = 1.074), suggesting that each additional year of experience increased the likelihood of adoption by approximately 7%. Education level significantly increased the probability of adoption ($P < 0.01$; OR = 1.543), indicating a greater capacity among more educated farmers to integrate technological innovations.

Socio-economic and production determinants. Household status was significantly associated with adoption status ($\chi^2 = 8.3024$; $P = 0.01575$), with a weak to moderate association strength (Cramer's $V = 0.197$). Native villagers represented the largest proportion among adopters (51.6%), compared with 21.4% among non-adopters.

Among the socio-economic and production variables included in the logit model, household size was the only variable with a positive and significant effect on adoption ($P < 0.05$; OR = 1.207). Larger households were more likely to adopt resistant cassava varieties. In contrast, cultivated area and farmer age had no significant effects on adoption.

Institutional and information-related determinants. Access to extension services showed a significant association with adoption status in the bivariate analysis ($\chi^2 = 5.0782$; p

TABLE 2. Association between selected farmer characteristics and adoption status of resistant cassava varieties (Chi-square test) in Tshopo Province, Democratic Republic of the Congo

Factors		Adoption status			Test	Cramer's V
		AD (%)	NAD (%)	Total (%)		
Education level	No schooling	3.60	4.40	8.00	χ^2= 11.319, df = 3, P-value = 0.0232*	0.277
	Primary	24.20	9.60	33.80		
	Secondary	37.20	18.40	55.60		
	Higher	2.00	0.60	2.60		
	Total (%)	67.00	33.00	100.00		
Cassava farming experience	1–5 years	5.20	2.20	7.40	χ^2= 0.35485, df = 2, P-value = 0.08374	0.287
	6–10 years	12.20	5.60	17.80		
	e" 11 years	49.60	25.20	74.80		
	Total (%)	67.00	33.00	100.00		
Access to extension services	No	54.40	29.40	83.80	χ^2= 5.0782, df = 1, P-value = 0.02423*	0.187
	Yes	12.60	3.60	16.20		
	Total (%)	67.00	33.00	100.00		
Household status in village	Native	51.60	21.40	73.00	χ^2= 8.3024, df = 2, P-value = 0.01575*	0.197
	Resident	14.60	11.00	25.60		
	Migrant	0.80	0.60	1.40		
	Total (%)	67.00	33.00	100.00		
Marital status	Single	5.80	2.00	7.80	χ^2= 3.4895, df = 3, P-value = 0.3221	0.081
	Married	54.80	28.60	83.40		
	Divorced	2.40	0.40	2.80		
	Widowed	4.00	2.00	6.00		
	Total (%)	67.00	33.00	100.00		
Perceived agricultural performance	Not satisfied	2.60	0.40	3.00	χ^2= 6.6592, df = 3, P-value = 0.08359	0.077
	Satisfied	36.20	16.00	52.20		
	Moderately satisfied	4.00	1.40	5.40		
	Very satisfied	24.20	15.20	39.40		
	Total (%)	67.00	33.00	100.00		

Note: *P < 0.05; **P < 0.01; ***P < 0.001

TABLE 3. Logit model results estimating the probability of adopting resistant cassava varieties

Factors	Estimate	Std. error	Z value	P-value	Odds ratio
(Intercept)	-0.80586	0.95963	-0.84	0.4010	0.447
AES (0/1)	0.21996	0.31591	0.696	0.4863	1.246
HS	0.1885	0.07702	2.447	0.0144*	1.207
CA (ha)	-0.04296	0.31582	-0.136	0.8918	0.958
TCP (0/1)	1.27946	0.36024	3.552	0.00038***	3.595
FE (Years)	0.07142	0.01935	3.690	0.00022***	1.074
Age (Years)	-0.01334	0.01045	-1.276	0.2018	0.987
AR (0/1)	0.27237	0.32189	0.846	0.3975	1.313
AT (0/1)	-0.55403	0.31871	-1.738	0.0822	0.575
AI (0/1)	-0.30592	0.32299	-0.947	0.3436	0.737
EL (ordinal)	0.43394	0.15539	2.793	0.00523**	1.543
PAP (ordinal)	0.51367	0.22240	1.893	0.0580	1.671

Note: *P < 0.05; **P < 0.01; ***P < 0.001

= 0.02423), although the strength of the relationship remained relatively weak (Cramer's V = 0.187). Farmers benefiting from extension support were proportionally more represented among adopters (12.6%) than among non-adopters.

However, institutional and information-related variables, including access to extension services, radio, television, and internet, did not show significant effects in the multivariate model.

Overall model quality. The overall model indicators confirmed the validity of the estimation. The likelihood ratio test was statistically significant (LR $\chi^2 = 45.3377$; $P < 0.01$), indicating the overall relevance of the model in explaining the adoption of resistant cassava varieties. McFadden's pseudo-R^2 (0.147) suggested a moderate explanatory power, consistent with logistic regression models estimated from survey data. The mean variance inflation factor (VIF = 1.014) indicated the absence of multicollinearity among the explanatory variables.

DISCUSSION

Adoption of cassava varieties resistant to viral diseases. The observed adoption rate of virus-resistant cassava varieties (67%) reflects a relatively advanced diffusion of resistant planting material among smallholder farmers in Tshopo Province. Nevertheless, adoption remained predominantly partial, as 55.6% of farmers combined local and resistant varieties within the same farming system. This pattern confirms the progressive and incremental nature of technological adoption in smallholder agriculture, where innovations are often integrated gradually rather than through complete replacement of existing practices (Foster and Rosenzweig, 2010; Suri, 2011).

In the context of the DRC, this coexistence of varieties reflects a trade-off between multiple dimensions of agricultural performance. Local cassava varieties remain preferred for their culinary and processing qualities, particularly for the preparation of local food products such as *foufou, lituma,* and *chikwangue*, while resistant varieties are mainly valued for their tolerance to viral diseases and their capacity to stabilise yields (Nweke *et al.*, 2002; Mahungu *et al.*, 2022). Adoption, therefore, does not correspond to a complete substitution process, but rather to a gradual integration of innovation into existing production systems. These findings suggest that the diffusion of resistant varieties depends not only on agronomic performance, but also

on their compatibility with local food preferences, processing practices, and farmers' production objectives.

Determinants of adoption of resistant cassava varieties

Human capital determinants. The results clearly demonstrate that human capital constitutes the main determinant of the adoption of resistant cassava varieties (Table 3). More specifically, technical training, farming experience, and education level emerged as the most influential factors explaining adoption behaviour.

Training in cassava production appeared to be the strongest determinant of adoption. This result confirms the central role of agricultural training and extension mechanisms in reducing information asymmetries and facilitating the diffusion of technological innovations (Anderson and Feder, 2007). Farmers who received technical training were more likely to understand the agronomic advantages of resistant varieties, their management requirements, and their potential contribution to reducing production risks. In rural contexts characterised by imperfect information, technical training also strengthens farmers' confidence in the innovation and their capacity to experiment with new planting materials. Similar findings suggest that participatory training approaches and local learning networks substantially improve the adoption of agricultural technologies (Wossen *et al.*, 2017; BenYishay and Mobarak, 2019).

Farming experience also exerted a positive effect on adoption, reflecting the importance of cumulative learning processes in smallholder farming systems. Experienced farmers are generally more capable of evaluating innovations through observation, experimentation, and comparison with existing practices (Bandiera and Rasul, 2006; Conley and Udry, 2010). Farming experience may facilitate the identification of varietal differences in terms of disease tolerance, productivity, and adaptation to local growing conditions (Mahungu *et al.*, 2022). This result suggests that adoption is partly shaped by experiential knowledge accumulated through repeated production cycles and long-term interaction with the farming environment.

Education level also positively influenced adoption, confirming that cognitive and informational capacities play a key role in the appropriation of agricultural innovations (Doss, 2006; Suri, 2011). More educated farmers are generally more capable of understanding technical recommendations, interpreting information related to improved varieties, and integrating innovations into their production strategies. In contexts where access to formal agricultural information remains limited, education may, therefore, enhance farmers' ability to process and utilise available knowledge more effectively.

Overall, these findings indicate that the adoption of resistant cassava varieties depends primarily on farmers' learning capacities. Strengthening human capital should constitute a central priority for policies aimed at accelerating the diffusion of resistant varieties. This implies promoting extension approaches that encourage active learning and direct farmer participation, including farmer field schools, village-level demonstration plots, and farmer-to-farmer knowledge exchange mechanisms.

Socio-economic and production determinants. Beyond human capital, household size also positively influenced the adoption of resistant cassava varieties (Table 3). This effect may reflect the greater availability of family labour in larger households, which facilitates experimentation and the simultaneous management of several cassava varieties within the same farm (Feder e*t al.*, 1985). Larger households may also benefit from broader social interactions and stronger integration into local exchange networks, improving access to planting material and production-related information

(Bandiera and Rasul, 2006). However, since resistant varieties often require additional labour during initial experimentation and integration, labour constraints may partly limit adoption by smaller households.

In contrast, cultivated area did not show a statistically significant effect on adoption. This finding challenges the conventional assumption that adoption mainly depends on farmers' resource endowments or wealth. In the context of Tshopo Province, this lack of significance may be explained by the widespread cultivation of cassava across farms of varying sizes and by the relatively limited constraints related to land access (Omasombo *et al.,* 2020; Mahungu *et al.,* 2022). These findings reinforce the idea that adoption of resistant varieties is driven more by farmers' capacities to learn and appropriate innovations than by differences in productive assets alone.

Institutional and information-related determinants. Institutional and information-related variables did not show statistically significant effects in the multivariate model. This finding suggests that passive access to information through media channels alone may be insufficient to stimulate adoption of resistant cassava varieties. In contrast, the significant role of training indicates that adoption depends more strongly on active learning processes involving direct interaction, technical support, and practical experience. Previous studies have shown that interpersonal communication and participatory extension approaches are generally more effective than passive information dissemination in promoting agricultural innovation adoption (Beaman *et al.*, 2014; Magnan *et al.*, 2015).

Implications for the promotion of adoption. The findings of this study carry important implications for agricultural policies and innovation dissemination strategies in cassava-based farming systems. First, they demonstrate that improving farmers' access to information alone is unlikely to generate substantial adoption unless supported by effective learning mechanisms. The absence of significant effects for passive information channels contrasts with the strong influence of technical training and experiential learning variables.

Secondly, the results suggest that agricultural policy should mainly prioritise investments in human capital development. This includes strengthening farmer training programmes, improving the quality of extension services, and supporting participatory learning approaches adapted to local conditions. Farmer field schools, demonstration plots, and local farmer exchange networks may constitute particularly effective instruments for accelerating the adoption of resistant cassava varieties in rural areas characterised by imperfect information and limited institutional support.

The findings further suggest that adoption strategies should not focus exclusively on agronomic performance criteria. Resistant varieties are more likely to be sustainably integrated into farming systems when they also respond to local culinary preferences, processing requirements, and market expectations. Consequently, varietal development and dissemination programmes should better incorporate farmers' preferences and local usage patterns into breeding and diffusion strategies.

Limitations of the empirical approach. Given that the analysis was based on cross-sectional survey data, the relationships identified should be interpreted as conditional statistical associations rather than strict causal relationships (Angrist and Pischke, 2009; Wooldridge, 2010). In addition, adoption was measured using a self-reported binary variable, which did not capture the actual intensity of resistant variety use and may, therefore, lead to some overestimation of adoption levels (Doss, 2006).

These limitations suggest that future research could mobilise longitudinal data or

more advanced econometric approaches to better analyse the dynamics and intensity of adoption processes over time.

CONCLUSION

The results show that the adoption of cassava varieties resistant to viral diseases in Tshopo Province is relatively widespread, with 67% of farmers reporting the use of at least one resistant variety. However, adoption remains predominantly partial, as 55.6% of producers combine local and resistant varieties within the same farming system. Beyond this adoption pattern, the analysis clearly demonstrates that human capital constitutes the primary driver of adoption. More specifically, technical training in cassava production emerged as the most influential factor, followed by farming experience, educational attainment, and household size. These findings indicate that farmers' learning capacities play a central role in the adoption process, well beyond productive assets or passive forms of information access.

From an agricultural policy perspective, these results suggest that improving the adoption of resistant cassava varieties requires strengthening human capital as a central priority. The most effective interventions are likely those that promote active learning processes, particularly through technical training in cassava production, participatory extension approaches, demonstration plots, and farmer-to-farmer knowledge exchange mechanisms. Such interventions may contribute not only to improving farmers' understanding of resistant varieties, but also to facilitating their gradual integration into local production systems.

Overall, this study highlights that the diffusion of varietal innovations in smallholder farming systems depends fundamentally on learning processes. Strengthening farmers' technical and cognitive capacities should therefore constitute a central priority for achieving sustainable adoption of resistant cassava varieties in the DRC and similar contexts.

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