

RESEARCH



Farmer typology and adoption of improved cassava production technologies in the Eastern Democratic Republic of the Congo

Nsharwasi Léon Nabahungu¹, Jackson Cirhuza Mirali¹, Guy Simbeko^{1,2*}, Serge Amato¹, Gentil Murhabazi Mirali³, Patrick Minyangu Muhindo⁴, Charles Kitangala⁵, Fidele Barhebwa Balangaliza⁶, Paul-Martin Dontsop Nguezet⁷, Kokou Kintche¹, Patchimaporn Udomkun⁸, Jacob Mignouna¹ and Bernard Vanlauwe⁹

Abstract

This study aimed to examine the factors driving the adoption of improved cassava seeds and fertilizers among smallholder farmers in South Kivu and Tanganyika provinces, Eastern Democratic Republic of the Congo (DRC), using data from 1317 farming households. Data were analyzed using principal component analysis (PCA) and cluster analysis by classifying farmers based on their cassava agricultural practices while capturing their preferences, attitudes, and socioeconomic characteristics. Logistic regression was then applied to evaluate the adoption of improved cassava seeds and fertilizers across different farmer-type groups. Therefore, farmers were classified into five distinct groups in both provinces. In general, for cassava-improved seed, farming experience increases its adoption by 15.1% per year in Cluster 5. At the same time, primary education boosts adoption in Cluster 1 by 17.4%, and university education raises it by 20.1% in Cluster 5. Larger land areas significantly enhance adoption by 46.9% in Cluster 4 and 79.6% in Cluster 1, reflecting the benefits of larger farms. Livestock ownership raises adoption by 26.8% in Cluster 1, highlighting the value of assets in agricultural investment. Agriculture training and income are highly effective, improving adoption by 18.2% in Cluster 5 and 8% overall. Specifically, in South Kivu, gender influences fertilizer adoption by 18.0% (Cluster 1) and 14.9% (Cluster 5) while marital status enhances fertilizer adoption and with being married raising the probability by 0.52% (Cluster 4). These findings emphasize the importance of education, gender, income resource access, and targeted interventions to improve agricultural technology adoption. Furthermore, promoting farmer engagement in agricultural activities is recommended through enhanced extension services and cooperative memberships.

Keywords: cassava agricultural practices, cassava planting materials, fertilizer application, multivariate analysis, farm typology

Introduction

Cassava plants (*Manihot esculenta Crantz*) play a significant role as an efficient and economical source of income, nutrients, and energy in cropping systems (Humpal *et al.*, 2012; Mekonnen *et al.*, 2023). In Eastern Africa, cassava roots are a crucial food source, supplying more than 55% of the population's daily calories. In the Democratic Republic of the Congo (DRC), about 70% of the population relies on cassava as a staple crop (Humpal *et al.*, 2012; Oloruntola, 2020). It is a food security crop because it can be

harvested from 8 to 24 months after planting and can be left on the ground as a safeguard against unexpected food shortages (FAO, 2022). Moreover, the degree of its possible advantages differed based on the farmers' acceptance and application of enhanced agricultural technology that boosts output. However, the average yield of cassava in the Eastern DRC is still lower (8 t ha⁻¹) than its potential yield, which is close to 50 t ha⁻¹ (Munyahali *et al.*, 2017). Research highlights several challenges in cassava production, including low-input practices, poor soil fertility, and suboptimal

Affiliations: ¹International Institute of Tropical Agriculture (IITA), Bukavu, P.O. Box 062, Democratic Republic of the Congo; ²Faculty of Economics and Management, Université Catholique de Bukavu (UCB), Bukavu, P.O. Box 285, Democratic Republic of the Congo; ³Food and Agriculture Organization of the United Nations, Bukavu, Democratic Republic of the Congo; ⁴Food and Agriculture Organization of the United Nations and Regional Post-Graduate Training School on Integrated Management of Tropical Forests and Lands (ERAIFT), Kinshasa, Democratic Republic of the Congo; ⁵International Institute of Tropical Agriculture, Kalemie, Democratic Republic of the Congo; ⁶Earth and Life Institute, Université Catholique de Louvain, Louvain-la-Neuve, Belgique; ⁷International Institute of Tropical Agriculture, Mbuji-Mayi, Kasai Oriental, Democratic Republic of the Congo; ⁸Department of Environment Engineering, Faculty of Engineering and Thailand Office of Research Administration, Chiang Mai University, Chiang Mai, 50200, Thailand; ⁹International Institute of Tropical Agriculture, Ibadan, P.O. Box 20001, Nigeria

*Corresponding Author: Guy Simbeko. Email: simbeko.sadi@ucbukavu.ac.cd

Submitted: 25 November 2024. Accepted: 10 February 2025. Published: 10 March 2025



© The Authors 2025. Open Access. This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

management techniques. Additionally, there is often insufficient investment in resilient seed varieties and an effective extension system. The vegetative nature of cassava seeds makes them bulky, expensive to transport, and highly perishable. This situation raises transaction costs and restricts access to clean planting materials. Limited access to detailed weather information, poor farming practices, and the low use of recommended cassava production technologies are among the main factors causing the low productivity of cassava in the country (Nweke *et al.*, 2000; Ouma *et al.*, 2011; Humpal *et al.*, 2012; Kintché *et al.*, 2017; Kaluba *et al.*, 2021). In addition, cassava production is exacerbated by the low spread and use of good agricultural practices (GAPs) (Casinga *et al.*, 2021) and is affected by climate change in terms of drying of cassava plants, and increased incidences of pests such as mealy bugs and white flies. The latter results in increased incidences of diseases such as cassava brown streak disease (CBSD) which leads to reduced yield as root tubers are rotten, affecting the quantity and quality of planting stems. The scarcity of cassava planting materials is affected by CBSD, eventually, leading to low cassava production, which can result in food insecurity (Casinga *et al.*, 2021). This underscores the urgent need to understand the factors driving the adoption of improved cassava inputs. Framing these global and regional challenges sets the stage for addressing the specific issues faced by Congolese cassava farmers, highlighting how these broader constraints affect them locally and supporting the study's focus on technology adoption and farmer diversity. To address these limitations, it is crucial to develop and adopt high-yielding crop varieties and utilize GAPs.

Hence, efforts are being made by the government, local and international organizations, and donors to introduce high-yielding cassava varieties that are tolerant to pests and diseases in Eastern Africa, including the Eastern DRC (Harry and Otto, 2019). The adoption of cassava farming practices and income were the subject of previous studies conducted in DRC and around the world (Tahirou *et al.*, 2015; Kilwinger *et al.*, 2021). Some researches laid specific emphasis on the adoption of pest and disease management practices (Casinga *et al.*, 2021) and the impact of GAPs on income and poverty (Dontsop Nguetzet *et al.*, 2020), respectively. The benefit of cassava production for food security (Vurro *et al.*, 2010; Muengula-Manyi *et al.*, 2012; Ezui *et al.*, 2017; Munyahali *et al.*, 2017; Mubalama *et al.*, 2019; Onyemma *et al.*, 2019; Kreye *et al.*, 2020; Onasanya *et al.*, 2021) and the reasons for considering diversity as an important factor within this gap need to be determined. This research attempted to fill this gap – at best – by providing knowledge on the influence of farmer diversity on the adoption of cassava production technologies. The study suggests that differences in adopting cassava agricultural technology in the context of Eastern DRC may be linked to the diversity of farmers in terms of their GAPs and socioeconomic characteristics.

Hence, this study aimed to evaluate the diversity among farmers in terms of the adoption of improved cassava planting material and fertilizers in DRC. Specifically, the study aims to assess the diversity among farmers based on their cassava production practices by using a multivariate approach to develop farm typologies in order to provide valuable insights into different cassava farmers types based on their cassava production practices in Eastern DRC. Furthermore, the study wants to identify the socioeconomic factors that influence the adoption of improved cassava planting materials and fertilizer across different cassava farmer types by using logit regression analysis to provide an understanding of the variables that affect the adoption of improved cassava technology. This approach provides key insights for designing targeted agricultural interventions and assessing technology adoption, scaling readiness, and best agriculture practices in the DRC. After the introduction, the next section outlines the methods, the third section reports the results of the data analysis, the fourth section

discusses the study's conclusions, and the final section is devoted to the paper's conclusions.

Methods

THEORETICAL ANALYTIC CONCEPT OF FARMERS' TYPOLOGY

Farmer typology is a procedure for identifying a group of farms that are different in terms of resource endowments (Goswami *et al.*, 2014). Various classification schemes, both qualitative and quantitative, have been developed to capture the diversity among farmers, given the socioeconomic characteristics and biophysical circumstances that make up their endowments. Hence, scholars have distinguished three main kinds of typology (Alvarez *et al.*, 2018; Yannick *et al.*, 2019; Tittone *et al.*, 2020). The first one is the systematic comparison of the farm's functioning. This approach is based on identifying farm types using criteria from local actors or data analysis from farm household surveys (Alvarez *et al.*, 2014b; Khandoker *et al.*, 2022). The second is the expert knowledge typology, which is based on the participatory ranking technique. This latter construction technique utilizes farm clusters identified by farmers, local experts, and key informants. It involves classifying households based on observable assets by experts, and it can be applied over a short-term period. Finally, multivariate analysis methods use data and statistical techniques such as principal component analysis (PCA), considered dimensional data reduction, and clustering analysis (CA), which categorizes smallholder farming practices (Hair, 2009). Alvarez *et al.* (2014b) defined PCA as a top algorithm for data selection, aiming to decrease the data size, remove noise, and extract meaningful, interpretable information for further analysis. It transforms the data variables into principal components. In this research, we utilized PCA due to its statistical replication potential, and widespread preference over other approaches (Musafiri *et al.*, 2020). In this study, reconciling typology based on cassava practices with farming household socioeconomic characteristics can help guide policies and intervention measures, as well as promote and scale up cassava agricultural technologies in the Eastern DRC.

SAMPLING AND DATA COLLECTION

This study was conducted in 11 basins in South Kivu and Tanganyika provinces in the Eastern DRC. The choice of cassava production basin was dictated by the nutritional, economic, and sociocultural importance of the cassava plants. The selected basins possess conducive agroecological characteristics for cassava cultivation, and they host major local, national (INERA-Mulungu, INERA-Emilingombe, ITAV), and international agricultural research centers (IITA, CIAT) and nongovernmental organizations (FAO), which promote improved crop varieties, including cassava, as well as good agricultural practices (GAPs). The data collection was preceded by pre-surveys in each of the basins to obtain information on the number of cassava farmers and an exhaustive list of farmers benefiting from improved cassava dissemination programs. With the assistance of key informants, such as leaders of farmers' associations, local authorities, extension agents, and representatives of farmers' support structures, we were able to identify 46,150 and 21,070 farmers who grow and market cassava, respectively, in South Kivu and Tanganyika. Agricultural inspection services (Services d'inspection agricole [SIA]) proposed including a larger number of cassava farmers from two provinces. After discussion, we collectively decided to select a sufficient number of farmers to avoid unnecessary costs, logistical challenges, and potential ethical and security issues.

We selected the respondents based on the proportion of the sample units in each basin. As a result, we chose randomly 972 farmers in South Kivu and 345 in Tanganyika, for a total sample size of

1317 respondents. Sampling was, therefore, random (probability sampling), which involved a random selection of cassava farmers based on the convenience of SIA that allows us to easily collect project data. SIA selected cassava farmers from their existing database. Hence, random sampling minimizes selection bias, as every farmer in the population or sampling frame has an equal chance of being chosen.

The data collection involved conducting individual interviews and field observations utilizing semi-structured survey questionnaires programmed in the Open Data Collection Kit (ODK). The survey encompassed several key aspects, including farmer GAPs, characteristics of the farmer's household, such as gender, age, education level, and marital status, number of income sources, household monthly income, food-purchasing habits, and primary occupation. Farm-related features included total land size, land ownership, and ownership of improved livestock. This study collected information on the use of hired and family labor on cassava farms, as well as access to training on agriculture, breeding, and cassava processing. In addition, wealth-related attributes such as the average monthly food self-sufficiency period of households from their own fields, food-purchasing habits, and the number of livestock species owned were documented. Specifics about cassava farming included data on cassava cultivation areas, management practices, and the use of improved cassava seeds. Information on pest and disease occurrence in cassava fields was also recorded, including the incidence of cassava anthracnose disease (CAD), cassava bacterial blight disease (CBB), cassava brown streak disease (CBSD), and cassava mosaic disease (CMD). All participants carried out the research with informed oral consent. The confidentiality of all the information from all the respondents was ensured. The study was conducted following the

guidelines set by the International Institute of Tropical Agriculture (IITA) Internal Review Board (IRB), and the work and protocols of the Regional Integrated Agricultural Development Project Great Lakes (PICAGL) were covered by ethics clearance.

STUDY AREA

This study was conducted from December 2019 to January 2021 in Tanganyika and South Kivu provinces in the Eastern DRC. It covered six cassava production basins in South Kivu (Walungu, Bunyakiri, Kalehe, Ruzizi Plain, Fizi, and Kabare) and five in Tanganyika (Kabimba, Katibili, Lwaminwa, Muhala, and Rugumba) (Fig. 1). These cassava production basins are located in a grassy savanna characterized by many streams and a mountainous tropical climate, where the temperature averages around 19°C and rainfall is bimodal, with annual totals ranging from 1300 to 1800 mm. There are clay and sandy soils, which are depleted and eroded. The population depends mainly on agriculture, livestock farming, and fishing for food and income. The main crops essential for livelihoods in the region are cassava, maize, sweet potato, sorghum, banana, and beans. Moreover, coffee, tea, and sugarcane are the major crops grown for commercial purposes. Cassava is an important part of many celebrations and daily meals. It is used as an additive in bread making and other high-quality products made from cassava flour.

The selection of South Kivu and Tanganyika provinces in Eastern DRC as study areas was intentional, reflecting cassava's critical role in nutrition, economy, and culture. Cassava serves as a primary food source, meeting over half of the region's caloric needs, while also contributing significantly to household incomes due to strong market demand. These areas are ideal for cassava farming, benefiting from favorable agroecological conditions,

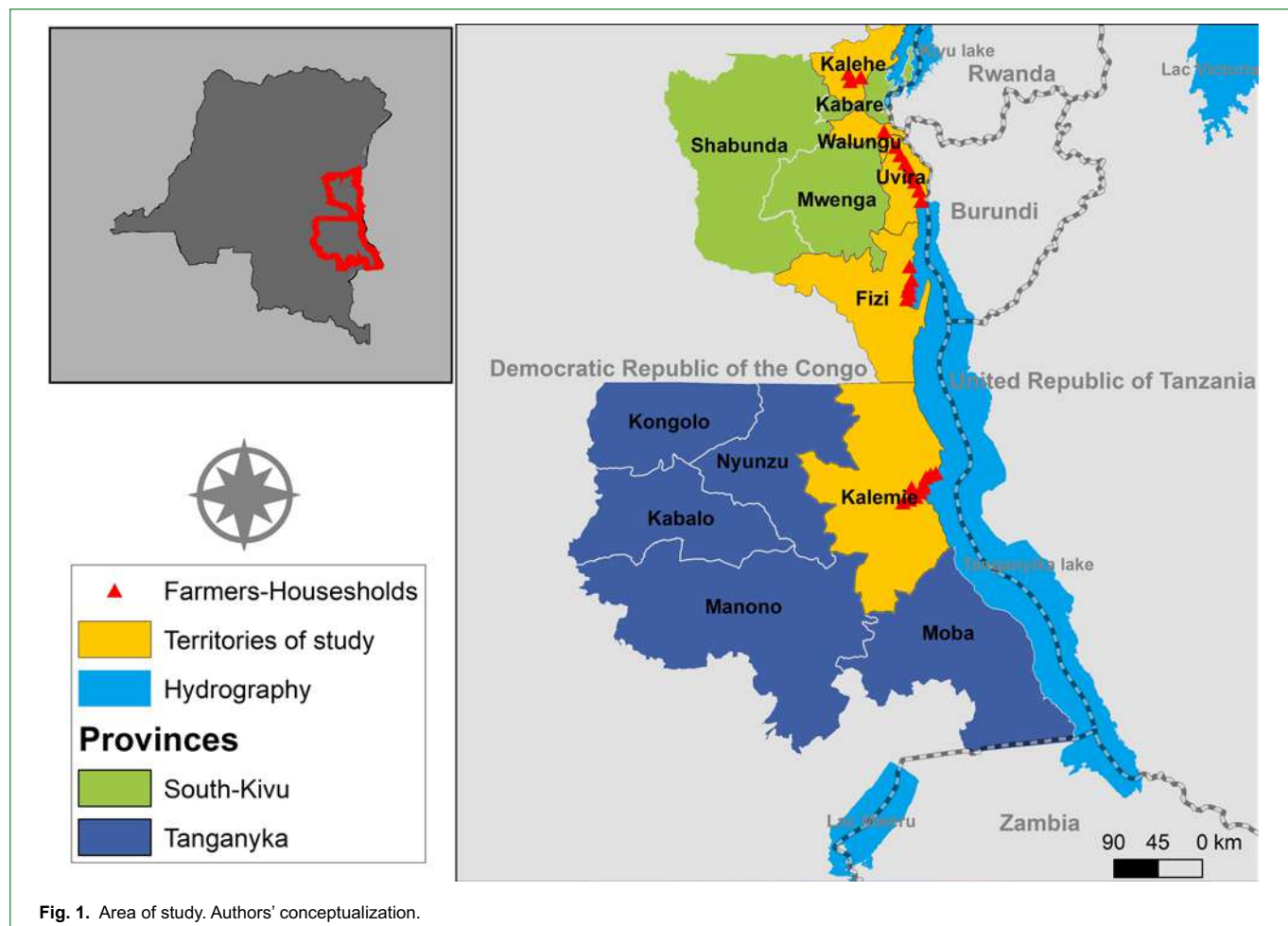


Fig. 1. Area of study. Authors' conceptualization.

including adequate rainfall, suitable soils, and a supportive climate. Cassava holds deep sociocultural significance, shaping diets and traditions. Key agricultural institutions promote improved varieties, making these regions vital for interventions. Selecting these provinces ensures that the study addresses technology adoption challenges, developing tailored solutions that recognize cassava's role in sustenance and economic well-being.

DATASET INVESTIGATION AND SELECTION OF THE MOST APPROPRIATE VARIABLES

Principal component analysis (PCA) was also conducted using orthogonal rotation (varimax) to investigate the dataset and select the most appropriate variables. The Kaiser-Meyer-Olkin (KMO) measure confirmed the adequacy of the sample for the analysis. The KMO value was estimated at 55% (0.55), harmoniously surpassing the minimum threshold of 0.5 (50%). To clarify, the KMO ratio indicates the suitability of the data for factor analysis. When a value of 0.55 was above the bare minimum, following the criteria outlined by other scholars (Hair, 2009; Revelle, 2017; Shrestha, 2021), variables with KMO ratios higher than 0.5 were removed from the analysis. Seven components (Table 2) had eigenvalues greater than Kaiser's criterion of 1.0, and the percentage of variance explained was 67%, which was greater than 60% and within the acceptable limits following Alvarez *et al.* (2014a), Makate *et al.* (2018), and Sarker *et al.*, (2021a) standards. To retain as much variability as possible in the dataset, we interpreted the first seven principal components, which accounted for nearly 67% of the total variance in the dataset. The number of principal components (PCs) retained was determined based on Kaiser's criterion: all PCs exceeding an eigenvalue of 1.0 were retained in coherence with Hertel *et al.* (2006). The appropriateness of the PCA was based on the Kaiser-Meyer-Olkin measure of sampling adequacy and Bartlett's test of sphericity: a value equal to or greater than 0.60 and a *P*-value < 0.05 indicated PCA adequacy, respectively, following the criteria of Mabe *et al.* (2019). To evaluate the adequacy of the correlations among the PCA variables, we used Bartlett's test of sphericity. The method involves calculating the determinant of the matrix of the sum of products and cross products, which is the equivalent of the chi-square statistic. Note that in PCA, the communality of a variable is the sum of the squares of the sum of products and cross products of a variable are the sum of the squares of factor loadings, whereas factor loading is the correlation between a variable and a factor (component).

CLUSTER ANALYSIS (CA) AND THE ADOPTION OF AGRICULTURAL TECHNOLOGIES

Cluster analysis (CA) was carried out using Ward's method to minimize the variance within a cluster. After clustering based on the adoption of GAPs, one-way ANOVA was used to test for significant differences between clusters for all variables in the categories of: (1) use of GAPs in cassava production, (2) socioeconomic characteristics, (3) household wealth attributes, (4) cassava farming attributes, (5) awareness of cassava practices, and (6) occurrence of pests and diseases in the cassava field. The variables from the last class were used to describe the farm type. The correlation of variables in each cluster is presented in an ellipse graph (Fig. 3). Moreover, logistic regressions were performed in STATA 14 within each cluster to evaluate the socioeconomic factors influencing the awareness and adoption of key improved cassava production technologies identified in the clusters, specifically focusing on the use of improved cassava seeds and fertilizers. The variance inflation factor (VIF) analysis (Table 8) was conducted for individual predictors to detect any significant multicollinearity and reduce variables in the model. Goodness-of-fit tests were conducted to evaluate the adequacy of the logistic regression models. The chi-square test (Prob > chi2) was performed, yielding *P*-values to attest to the models' robustness and highlight the significance of the included variables. Furthermore, the Akaike information criterion (AIC) was used to evaluate the model's fit and maintain a balanced consideration of complexity versus explanatory power.

DETERMINANT OF FARMER ADOPTION OF IMPROVED CASSAVA VARIETIES AND FERTILIZER

Logistic regression was used to identify the determinants of farmers' adoption of improved cassava seed and fertilizer in each cluster. Hill and Smith's analysis for mixed quantitative and qualitative variables was used because they have the advantage of capturing the complexity of farming systems by considering several farm dimensions at the same time and then by highlighting a few dimensions that are more explanatory of farm diversity (Alvarez *et al.*, 2014b). The total scores provided additional data for exploratory factor analysis. The farmers' decision to adopt improved cassava technologies was captured as a binary choice: 1 if the farmer adopted it and 0 otherwise (Mugumaarhahama *et al.*, 2021; Nguetzet *et al.*, 2011). Referring to Wooldridge's (2002) studies on the adoption of agricultural technologies, this study used the logit model to examine the factors influencing cassava farmers' decisions to adopt improved varieties and fertilizers by cluster. The binary logistic distribution for the use decision is defined as follows:

$$P_{if} = \frac{1}{1 + e^{-Z_{if}}} \quad (1)$$

In Equation 1, P_i is the probability of the i^{th} and f^{th} farmers adopting cassava technologies for improved variety (i) and fertilizer (f), respectively. Here, e is the natural logarithm base, and Z_{if} represents the function of a vector of n explanatory variables and is represented by:

$$Z_{if} = \beta_0 + \sum \beta_{if} X_{if} \quad (2)$$

The choice of technologies can be expressed as a function of observable variables in the following logit equation model:

$$Y_{if} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \dots + \beta_n X_n + e_{if} \quad (3)$$

where Y_{if} , in the case of this study, is the dependent variable (adoption of improved cassava seed or adoption of fertilizer). The variable takes the value 1 if the farmer is currently planting improved cassava seed/fertilizer and 0 if not for improved cassava seed and for fertilizer, respectively. X , as a socioeconomic factor, is the matrix of variables likely to explain the variation in Y (Table 1). Based on the literature review, these socioeconomic and demographic variables are determinants of farmers adopting agricultural technologies because they can affect farmers' use of improved cassava seed and fertilizer technologies. β_0 is the Y-intercept, whereas $\beta_1 \dots \beta_n$ are a set of coefficients to be estimated, and $X_0 \dots X_n$ are the explanatory variables hypothesized to influence adoption decisions. Estimating equations separately for these two technologies allowed for a precise assessment of the unique determinants associated with each adoption decision.

Results

SOCIOECONOMIC CHARACTERISTICS OF THE FARM HOUSEHOLDS

Table 1 indicates that male heads of household (51%) lead most farm households within the entire sample. Specifically, in Tanganyika Province, there was a greater proportion of male-headed households (62%) than in South Kivu Province (47%). The heads of agricultural households have an average age of 44 years, indicating that they are predominantly adults, with only a small age difference between the provinces. According to the survey data, a significant majority of these farmers, 79%, are married. This result suggested that, like the head of the household, the farmer's wife could also undertake various farm management responsibilities. In addition, the average size of the farm households is eight people, and the number of farm households varies slightly according to the location where the farmers lived, from nine people per household in South Kivu Province to eight in Tanganyika Province. Regarding education level, descriptive analysis illustrated that the household head had an average of 6 years of schooling.

Table 1. Variables related to the socioeconomic characteristics of cassava farmers and the adoption of improved cassava production technologies.

Variable	Description and unit	Count (N=1317)	South Kivu (N=965)	Tanganyika (N=352)	Mean	SD	(T-test)
Adoption of improved cassava production technologies							
Planting after fallow (Dummy %)	1 if Cassava planted after fallow sowing season, 0 otherwise	575	32.16	75.43	43.66	0.497	(195.58)***
Planting after specific crop (Dummy %)	1 if Cassava is planted after a specific crop, 0 otherwise	634	52.33	36.57	48.14	0.311	(25.55)***
Use of fertilizer (Dummy %)	1 if fertilizer, 0 otherwise	274	28.13	0.57	20.8	0.409	(118.44)***
Use of tractor (for land preparation) (Dummy %)	1 if a tractor is used, 0 otherwise	151	11.38	11.71	11.47	0.318	(0.029)
Mono-cropping system (Dummy %)	1 if Cassava planting under a mono-cropping system, 0 otherwise	457	35.47	31.57	34.7	0.476	(0.953)
Line planting (Dummy %)	1 if Cassava line planting, 0 otherwise	107	2.79	22.86	8.12	0.271	(138.60)***
Used improved cassava seed during the last 5 years	1 if Cassava-improved variety, 0 otherwise	901	71.35	60.29	68.4	0.466	(14.57)***
Land clearing/Weed control (Dummy %)	1 if land clearing within weed control, 0 otherwise	30	2.07	2.86	2.28	0.154	(0.718)
Use of planting space (1 m x 1 m) (Dummy %)	1 if 1mx1m theoretical spacing, 0 otherwise	341	25.75	26.29	25.89	0.441	(0.038)
Awareness of pests and disease control (Dummy %)	1 if Aware of pests and disease control techniques, 0 otherwise	76	6.41	4	5.77	0.221	(2.748)*
Select site with average soil fertility status (Dummy %)	1 if the soil selected is perceived as average by farmers, 0 otherwise	832	60.97	69.43	63.22	0.482	(7.899)**
Select site with excellent soil fertility status (Dummy %)	1 if soil is perceived as excellent by farmers, 0 otherwise	422	34.27	26.0	32.07	0.466	(8.056)**
Use in the last 2 seasons cassava-improved seed	A number of quality-declared seed were used for at least 2 seasons	1302	6	6	6	4.021	(1.27)
Socioeconomic characteristics							
Male household head (Dummy %)	1 if Male household head, 0 otherwise	675	47.26	62.29	51.25	0.499	(23.224)***
Household size (Mean)	number of household members	1317	9	8	8	3.609	(2.56)***
Marital status (Dummy %)	1 if the household head is married, 0 otherwise	1317	77.25	84.86	79.3	0.408	(9.052)***
Age of the household head (Mean)	household head age in years	1317	42.8	45.45	43.54	13.97	(2.986)***
Education level							
Illiterate/no education (Dummy %)	1 if the household head is illiterate, 0 otherwise	370	33.09	14.29	28.09	0.448	(44.992)***
Primary school level (Dummy %)	1 if household head with primary school level, 0 otherwise	378	24.72	39.71	28.7	0.452	(28.25)***
High school level (Dummy %)	1 if the household head with high school level, 0 otherwise	540	24.72	39.71	41	0.493	(3.378)*
University level (Dummy %)	1 if household head with university level, 0 otherwise	29	2.69	0.86	2	0.144	(4.003)**
Average years of education (Mean)	average number of years of education	1317	5.9	6.5	6	4.297	(2.130)**
Household heads occupations							
Breeding (Dummy %)	1 if the farmer's main livelihood is breeding activity, 0 otherwise	4	0.31	0.29	0.30	0.055	(0.005)

Continued

Table 1. Continued.

Variable	Description and unit	Count (N=1317)	South Kivu (N=965)	Tanganyika (N=352)	Mean	SD	(T-test)
Office worker (Dummy %)	1 if the farmer's main livelihood is staff service, 0 otherwise	25	2.38	0.57	1.9	0.142	(4.506)*
Trading (Dummy %)	1 if the farmer's main livelihood is trading; 0 otherwise	14	1.24	0.57	1.06	0.103	(1.095)
Farming (Dummy %)	1 if the farmer's main livelihood is farming activity, 0 otherwise	1248	94.42	95.71	94.76	0.226	(0.872)
Income							
Number of sources of revenue (Mean)	Average number of household sources of revenues	1317	2	2	2	0.585	(2.639)**
Average income < 100 USD (Dummy %)	1 if income trench is under 100 USA dollars, 0 otherwise	642	50.88	42.86	48.75	0.5	(6.619)**
Average income 100 USD–300 USD (Dummy %)	1 if the income trench is between 100 and 300 dollars, 0 otherwise	453	31.02	43.71	34.4	0.474	(18.341)***
Average income 300 USD–500 USD (Dummy %)	1 if the income trench is between 300 and 500 USA dollars, 0 otherwise	144	11.69	8.89	10.93	0.309	(2.111)
Average income over 500 USD (Dummy %)	1 if income trench is over 500 USA dollars, 0 otherwise	78	6.41	4.57	5.92	0.235	(1.561)
Land ownership							
Heritance land (Dummy %)	1 if the land acquisition mode is inheritance, 0 otherwise	849	66.8	58	64.46	0.478	(8.696)***
Buy land (Dummy %)	1 if the land acquisition mode is buying, 0 otherwise	525	44.88	26.0	39.86	0.49	(38.216)***
Rent land (Dummy %)	1 if the land acquisition mode is buying, 0 otherwise	55	5.17	1.43	4.18	0.207	(8.992)***
Borrow land (Dummy %)	1 if the land acquisition mode is borrowing, 0 otherwise	260	17.27	26.57	19.74	0.394	(14.032)***
Household wealth attributes							
Farm food sufficiency period (Mean)	Average monthly periods of sufficiency food from household fields	1317	10	9	10	3.041	(0.986)
Buying food sufficiency period (Mean)	Average monthly periods of sufficiency from buying food	1317	9	9	9	3.42	(1.160)
Number of livestock (Mean)	Average number of livestock species	1317	3	3	3	1.912	(0.427)
Cassava farming attributes							
Total cassava land area (Mean)	Household's annual land area planted to cassava in hectare (ha)	1317	0.33	0.41	0.35	0.318	(4.045)***
Average number of hoeing tools (Mean)	Average number of hoeing tools	1317	5	4	4	4.507	(0.803)
Average Hired casual labors (Mean)	The average number of hired people per hectare and farm activity	1317	2	4	3	2.638	(9.319)***
Average Family Labors (Mean)	The average number of family members per hectare and farm activity	1317	1	2	1	1.475	(14.608)***
Years of cassava farming experience (Mean)	Average years of experience in cassava farming	1317	15	13	14	13.352	(2.226)**
Cassava as cash and consumption crop (Dummy %)	1 if cassava is considered a cash and consumption crop, 0 otherwise	1045	79.52	78.86	79.35	0.398	(0.069)
Cassava as cash crop only (Dummy %)	1 if cassava is considered a cash crop for the household, 0 otherwise	30	1.76	3.17	2.28	0.144	(4.418)**
Cassava as consumption crop only (Dummy %)	1 if cassava is considered a consumption crop, 0 otherwise	242	18.72	17.43	18.38	0.38	(0.284)

Awareness of cassava practices									
Training on agriculture practices (Dummy %)	1 if household head received training on cassava production, 0 otherwise	379	26.37	35.43	28.78	0.454	(10.288)***		
Training on cassava processing (Dummy %)	1 if household head received training on cassava processing, 0 otherwise	24	2.28	0.57	1.82	0.137	(4.169)**		
Number of cassava varieties used actually (Mean)	The average number of improved cassava varieties known	1317	2	2	2	0.845	(4.987)***		
Improved variety selection criteria									
High root yield (Dummy %)	1 if cassava-improved variety is high root yield, 0 otherwise	1016	75.8	80.86	77.15	0.421	(3725)*		
High leaf yield (Dummy %)	1 if cassava-improved variety is high leaf yield, 0 otherwise	434	33.4	31.71	32.95	0.47	(0.331)		
Storage ability (Dummy %)	1 if cassava-improved variety can be stored for a long period, 0 otherwise	252	20.27	16	19.13	0.392	(3.026)*		
Diseases resistant (Dummy %)	1 if cassava-improved variety is disease resistant, 0 otherwise	516	40.33	36	39.18	0.487	(9.052)***		
Taste (Dummy %)	1 if cassava-improved variety is tasteful, 0 otherwise	505	36.92	42.29	38.34	0.485	(3.131)*		
Source of improved seed									
Research (Dummy %)	1 if the cassava source of improved variety is the research center, 0 otherwise	428	35.06	25.43	32.50	0.468	(10.860)***		
Friend (Dummy %)	1 if cassava source of improved variety is friend, 0 otherwise	877	63.9	74	66.59	0.47	(11.762)***		
Parent (Dummy %)	1 if cassava source of improved variety is parent, 0 otherwise	403	30.51	30.86	30.6	0.46	(0.0149)		
Incidence of pest and disease in cassava field									
Incidence of rodents in the field (Dummy %)	1 if the incidence of rodents in the cassava field, 0 otherwise	851	65.56	62	64.62	0.479	(1.427)		
CAD incidence (Dummy %)	1 if the incidence of cassava anthracnose disease (CAD), 0 otherwise	19	1.55	1.14	1.44	0.119	(0.301)		
CBB incidence (Dummy %)	1 if the incidence of cassava bacterial blight disease (CBB), 0 otherwise	47	4.03	2.29	3.57	0.186	(2.280)		
CBSD incidence (Dummy %)	1 if the incidence of cassava brown streak diseases (CBSD), 0 if not	208	15.41	16.86	15.79	0.366	(0.405)		
CMD incidence (Dummy %)	1 if the incidence of cassava mosaic disease (CMD), 0 otherwise	879	65.25	70.86	66.74	0.472	(3.635)*		
Disease incidence general (Dummy %)	1 if no disease incident in the cassava field, 0 otherwise	164	13.75	8.86	12.45	0.329	(5.652)**		

Note: Fisher's and Student's t-tests were performed. Data were collected from selected smallholder farmers in the Eastern DRC in the South Kivu and Tanganyika provinces. Significance codes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Among the farmers, 72% had a primary, secondary, or university education. The proportion of farmer heads illiterate was greater for South Kivu (33%) than for Tanganyika (14%). Almost half (49%) of the farmers' households (with an average of approximately eight people per household) live on a monthly income below USD 100. Approximately 34% of households reported an average monthly income between USD 100 and USD 300. However, 11% of the respondents had an average monthly income between USD 300 and USD 500, and only 6% reported an average monthly income exceeding USD 500. In terms of land access, the cropping area was collected in hectares (Table 1), and the household's mean annual land area planted with cassava in hectares (ha) was 0.4 in Tanganyika and 0.3 in South Kivu. The data also illustrate that 64% of farmers possess their land through inheritance, while 40% acquire land through purchase. Only 24% did not own the land. The latter may borrow land from others or rent it. Most of the households reported having enough food for ten months while working in their fields and an average of nine months when purchasing food, with two months of food inadequacy.

FARMING PRACTICES OF FARM HOUSEHOLDS

Table 1 highlights two important practices adopted by most farmers in both South Kivu and Tanganyika provinces. The first is the use of improved cassava seeds to capitalize on the season. Regarding the use of improved cassava varieties, the comprehensive analysis indicated that most farmers (68%) employ improved varieties of cassava. The adoption rate of improved varieties was greater in South Kivu Province (71%) than in Tanganyika province (60%). This suggests that agricultural support services, agriculture awareness campaigns, and access to improved seeds vary considerably according to different socioeconomic conditions between the two areas. For land selection, the survey revealed that 63% of farming household heads chose a land with a good state of fertility. Agricultural practices such as post-fallow cropping systems and crop rotations are specific to each province. A post-fallow cropping system is used by 75% of farmers in Tanganyika, whereas this system is used by only 32% of farmers in South Kivu. On the other hand, crop rotation is more commonly practiced by farmers in South Kivu, with 52% of farmers cultivating their farms following a specific crop, compared to 37% in Tanganyika Province. Additional practices such as monoculture systems, fertilizer use, and tractor and row cropping are less common among farmers in both provinces. For example, 35% of farming household heads practice monoculture, cultivating a single plant species on their farms. The level of adoption of this practice did not significantly differ between the provinces of South Kivu and Tanganyika. Survey data also show that only 21% of farmers use fertilizer. The level of fertilizer use is even lower in Tanganyika (0.6%) than in South Kivu (28%). In addition, the level of mechanization on farms in the overall sample is still very low. For example, tractors were utilized by only 11% of farming households for field preparation overall.

SELECTION CRITERIA FOR IMPROVED CASSAVA VARIETIES

The survey's overall findings indicate that a significant proportion (77%) of farmers prioritize root yield when deciding which varieties to cultivate, followed by the resistance of the seeds to various plant diseases (39%). Farmers in South Kivu Province (40%) took the strength of a variety's resistance to disease more strongly than those in Tanganyika Province (36%). In general, some farmers select varieties with good taste (38%) and cassava leaf yield (33%), while 19% select an improved variety because of its shelf life (Table 1).

STEPWISE CHARACTERIZATION OF CASSAVA FARMERS IN SOUTH KIVU AND TANGANYIKA

The survey was conducted in the provinces of South Kivu and Tanganyika over a year, with three visits (Fig. 2). The first visit took place 3 months after cassava planting, the second visit was carried out 6 months after planting (MAP), and the third visit was

conducted 9 MAP. The first visit involved a socioeconomic survey and field observation while the second and third visits focused solely on field observation. The socioeconomic survey gathered from farmer households number of useful information, including their main activities, average income, food self-sufficiency, agricultural production methods, field size, animal ownership, farmer experience, and constraints related to cassava production. During the first visit, field observations included recording cultivation techniques, measuring field size, collecting geographical coordinates, installing three dials (of 5 m × 5 m each), counting plants, observing diseases, assessing the incidence and severity of mosaic and brown streaks, and measuring plant characteristics. In addition, leaf samples were collected for laboratory analysis and weed identification. During the second visit, observations were conducted by way of recording cultivation activities, spotting/scrutinizing diseases, evaluating the incidence and severity of mosaic and brown streaks, and measuring plant characteristics. The third visit involved recording cultivation activities, spotting/scrutinizing diseases, evaluating the incidence and severity of mosaic and brown streaks, measuring plant characteristics, identifying weeds, harvesting cassava plants, counting marketable and nonmarketable tubers, and measuring tuber and leaf biomass as well as linear field metameres.

FARM TYPOLOGY BASED ON IMPROVED CASSAVA PRODUCTION TECHNOLOGY ADOPTION

A total of 14 PCs were produced, with the first seven explaining 62% of the variation. These components, having eigenvalues greater than or equal to 1, were retained for further analysis. Hence, the PCA of the nine variables related to the uptake of innovations resulted in the extraction of seven PCs (Fig. 3). Table 3 displays the factor loadings associated with various improved cassava production technologies and the selection of sites with excellent or average soil fertility (Fig. 5). In the last five seasons, the consistent use of improved seeds for each of these components exhibited correlation and factor loadings exceeding 0.44, aligning with established criteria from Fermont *et al.* (2010) and Makate *et al.* (2018). These findings fall within acceptable limits and demonstrate agreement with the above-mentioned criteria. Hence, the PCA of the nine variables related to Good Agricultural Practices (GAPs) resulted in the extraction of seven principal components (PCs) (Table 2), collectively explaining 67% of the total variance. The model demonstrated statistical significance within an acceptable threshold ($\chi^2 = 2963.3$, $P < 0.0001$). PCA was implemented as a dimensionality reduction technique to identify key variables contributing to the heterogeneity of cassava farming GAPs across distinct farmer typologies. Retention of principal components was based on Kaiser's criterion, selecting components with eigenvalues ≥ 1 . The suitability of PCA was assessed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity, ensuring data adequacy for multivariate analysis.

To classify farmers into homogeneous groups, Ward's hierarchical clustering method was employed, optimizing intra-cluster cohesion while maximizing inter-cluster separation. A dendrogram was generated to determine the optimal number of clusters based on agglomerative hierarchical clustering. The PCA (Principal Component Analysis) identified seven distinct components, each contributing to the overall variance in cassava production practices. The first component (Comp 1) explained the largest portion of the variance, accounting for 16%. This component was positively correlated with the use of a mono-cropping system, particularly in areas with average to excellent soil fertility, where farmers chose appropriate sites for planting cassava.

The second component (Comp 2) explained 11% of the variance and showed a correlation between the use of inorganic fertilizers and the practice of planting cassava after a fallow period. The third component (Comp 3) accounted for 9% of the variance and was associated with the adoption of line planting as well as the cultivation of cassava following either a short fallow period or a specific preceding crop. The fourth component (Comp 4)

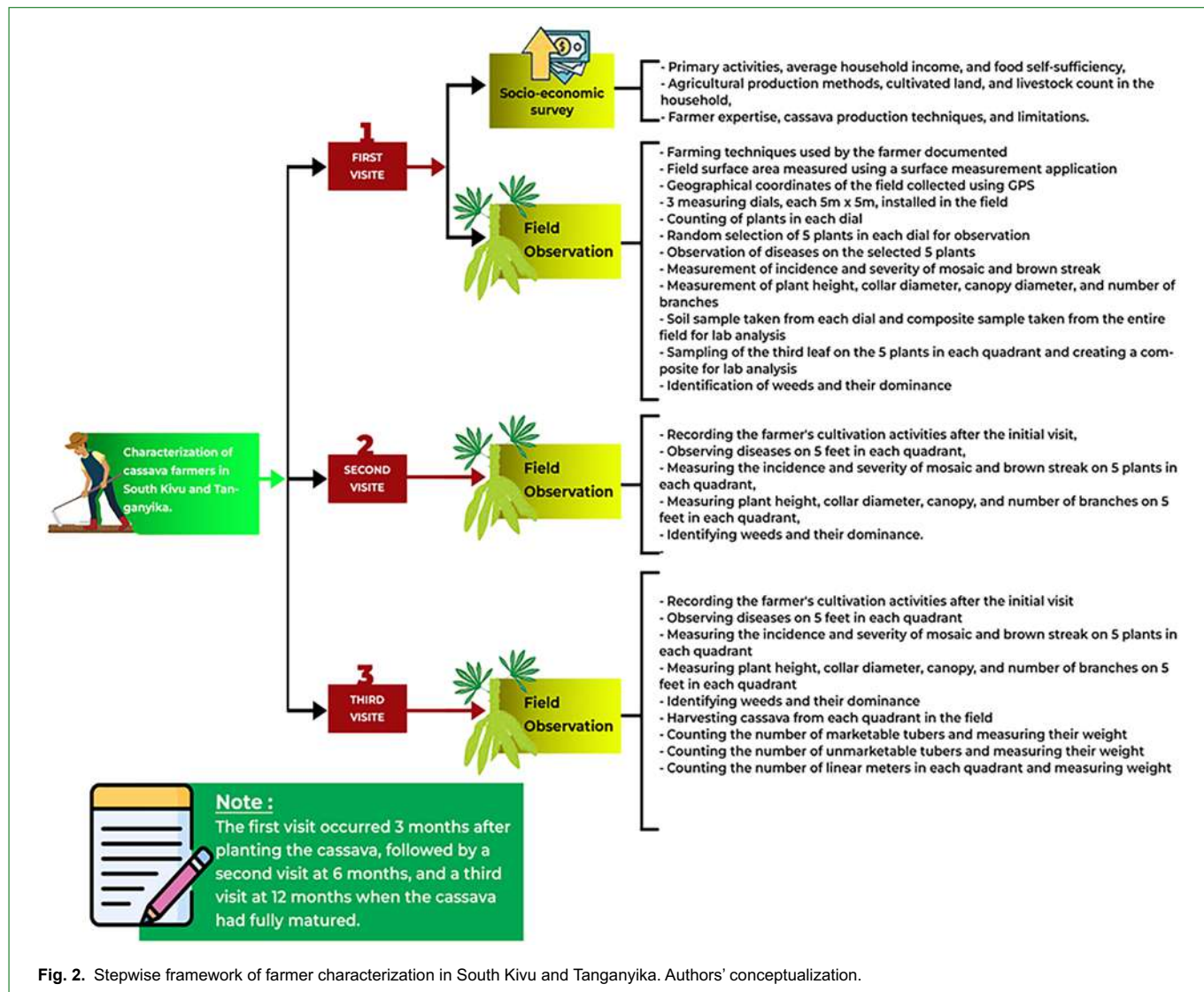


Fig. 2. Stepwise framework of farmer characterization in South Kivu and Tanganyika. Authors' conceptualization.

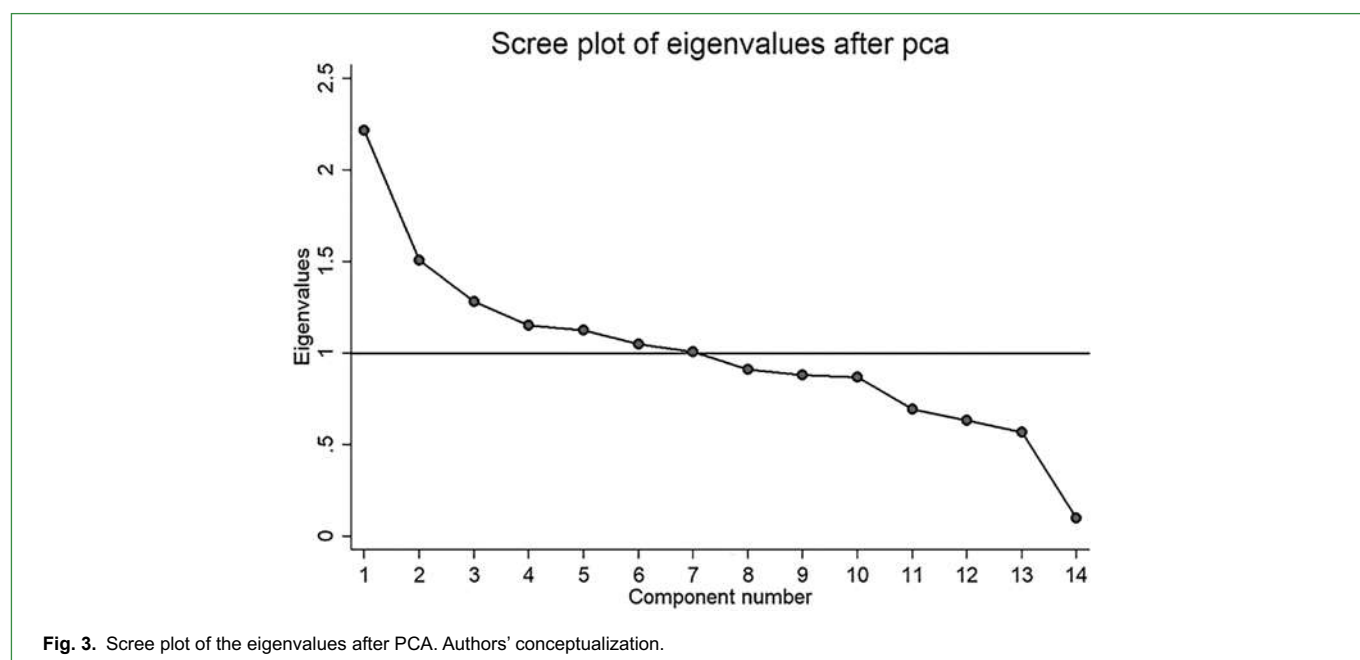


Fig. 3. Scree plot of the eigenvalues after PCA. Authors' conceptualization.

explained 8% of the variance and was linked to the use of specific planting spacing and an understanding of pest and disease control measures. Finally, the fifth component (Comp 5) also accounted for 8% of the variance and demonstrated a correlation between

the utilization of tractors and the adoption of improved cassava varieties. The sixth component (Comp 6) accounted for 8% of the variance and was related to land clearing and weed control practices. The seventh component (Comp 7) explained 7% of the

Table 2. Loadings from the seven components resulting from the principal component analysis with eigenvalues and percentages of variance explained.

Variables	Correlation between variables and a principal component						
	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 7
Time of planting and harvesting							
After fallow	-0.32	-0.60	0.08	0.33	0.16	0.14	0.04
After short fallow	0.00	0.23	-0.74	-0.08	0.02	-0.09	0.23
After specific crop	0.41	0.41	0.44	-0.08	-0.10	0.02	-0.21
Use input and agronomics fit practices							
Use of Fertilizer application	0.48	0.58	-0.02	-0.03	0.15	0.04	-0.01
Land preparation (use of tractor)	0.02	-0.05	-0.18	0.15	0.53	0.21	0.42
Use of a mono-cropping system	0.47	0.12	0.09	0.29	0.34	0.12	0.01
Use of Line planting	-0.10	-0.18	0.56	0.16	-0.06	-0.18	0.30
Used improved planting materials (varieties)	-0.13	0.10	0.01	-0.23	-0.60	0.11	0.54
Use of land clearing/weed control	-0.02	0.11	0.02	0.21	0.05	-0.84	0.24
Use of planting space (1 m × 1 m)	-0.05	-0.02	-0.23	0.49	-0.47	0.24	-0.19
Usage duration of improved variety	0.12	0.33	0.24	0.29	-0.04	0.35	0.47
Awareness of pests and diseases Control	-0.16	-0.18	0.16	-0.70	0.21	0.16	0.11
Site selection and farmer's soil fertility status appreciation							
Average soil fertility status	0.82	-0.47	-0.08	-0.08	-0.13	-0.04	0.09
Excellent soil fertility status	-0.84	0.45	0.09	0.06	0.12	0.03	-0.09
Eigenvalues	2.18	1.55	1.24	1.18	1.11	1.05	1.01
A portion of variance in percentage (%)	15.56	11.09	8.89	8.43	7.94	7.50	7.19
A cumulative portion of explained variance (%)	15.56	26.64	35.54	43.97	51.90	59.41	66.60
Chi 2	2963.3***						
P-value	0.000						
Df	91						

Notes: Comp = component. Factor loadings more or less 0.44 are marked in bold font. Data were obtained from selected smallholders in the Eastern DRC in Tanganyika and South Kivu provinces.

Significance codes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

variance, with the last eigenvalue measuring 1.0. This component is associated with the duration of use of improved cassava varieties over the last five seasons. These findings suggest that the adoption of these practices could help identify farms that belong to specific clusters.

The decision to select five clusters was informed by dendrogram analysis and expert understanding of the study areas. These clusters effectively represented real-world variations among smallholder cassava farmers. One-way ANOVA in Table 3 was used to test for significant differences in key variables, such as farm size, income, asset ownership, and adoption of improved cassava technologies. The statistical validation showed significant differences across clusters, confirming the meaningfulness of the classification. Furthermore, the cumulative portion of explained variance for each principal component was above 50% at the fifth cluster, ensuring robust and interpretable cluster distinctions for further analysis.

FARM TYPOLOGY CHARACTERIZATION FROM CLUSTER RESULTS

The ellipse in the graphic framework (Fig. 4) illustrates farmers within each cluster. Based on the P -values, various factors

significantly distinguished between the clusters of diverse farmer groups. Several factors were found to have a significant impact on differentiating farmers into distinct clusters. Several factors can influence agricultural productivity. These include the gender and age of the household head, the literacy level of the household head, marital status, educational attainment, the number of available farm laborers, the province in which the household is located, the number of family members working on the farm, land tenure status, awareness and adoption of improved cassava technologies, and the size of the farm. This highlights the importance of understanding and characterizing the diversity within the farmer population. As is also true for cassava farming attributes, farmers' training, household health attributes, awareness of cassava practices, sources of improved seeds, and occurrences of pests and disease were also significant (Table 3). This indicates that appropriate variables were chosen to construct farmer profiles according to their socioeconomic characteristics based on the adoption of cassava technologies. Table 3 categorizes farmers into five distinct clusters, each representing a specific farm type (referred to as Cluster I to Cluster V). The table summarizes the distinctive characteristics of each cluster, providing insights into the unique attributes and features that define each type of farm.

Table 3. Summary descriptive table by "cluster" in Tanganyika.

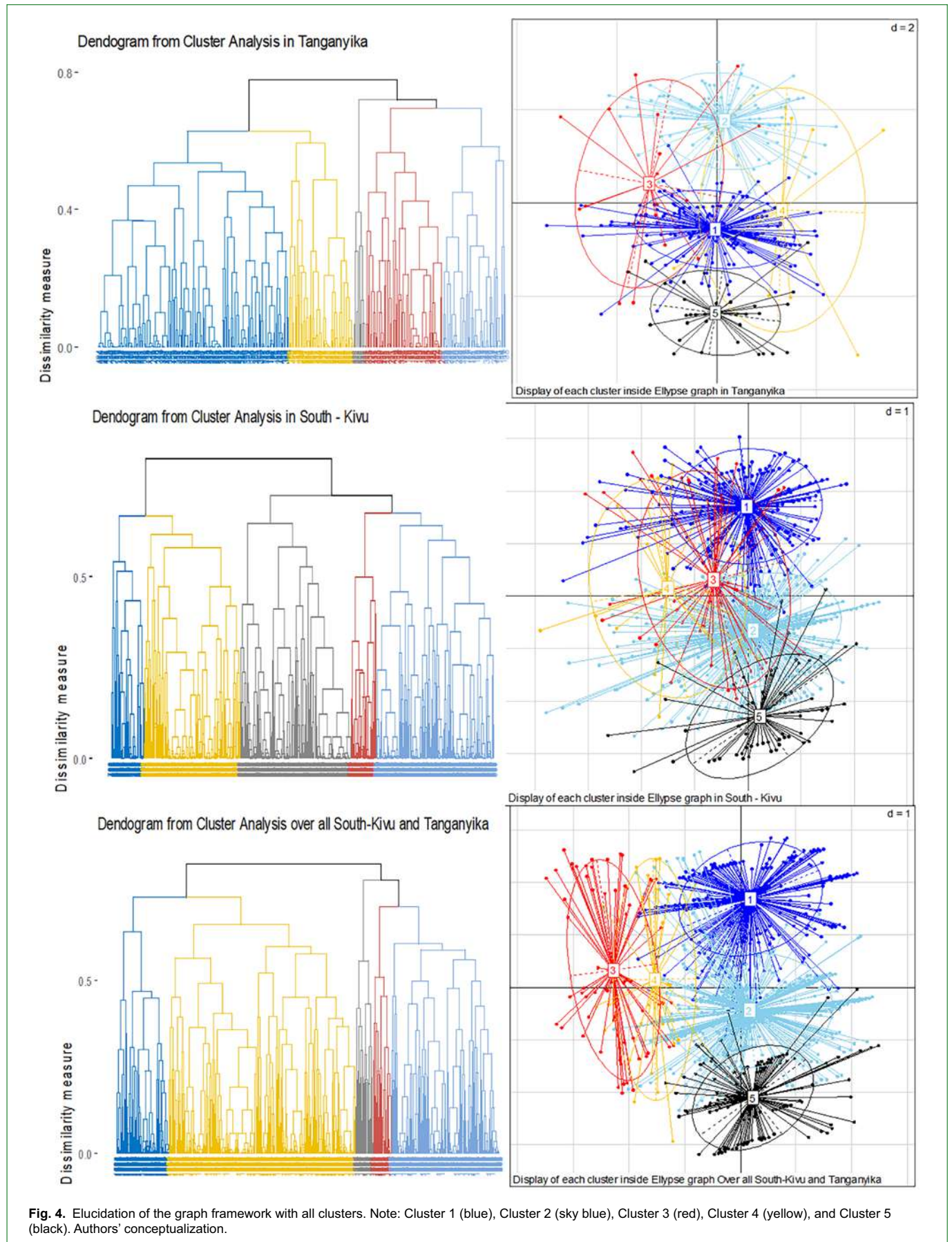
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	P overall	Sign
	N=86	N=45	N=76	N=93	N=50		
Adoption of improved cassava production technologies							
Planting after fallow	67 (77.9%)	36 (80.0%)	51 (67.1%)	77 (82.8%)	33 (66.0%)	0.068	*
Planting after a specific crop	8 (9.30%)	2 (4.44%)	10 (13.2%)	5 (5.38%)	3 (6.00%)	0.357	
Use of Fertilizer application	1 (1.16%)	0 (0.00%)	1 (1.32%)	0 (0.00%)	0 (0.00%)	0.753	
land preparation (Use of tractor)	12 (14.0%)	5(11.1%)	11 (14.5%)	8 (8.60%)	2 (4.00%)	0.293	
Mono-cropping system	36 (41.9%)	21 (46.7%)	20 (26.3%)	23 (24.7%)	13 (26.0%)	0.014	**
Line planting	24 (27.9%)	11 (24.4%)	20 (26.3%)	22 (23.7%)	3 (6.00%)	0.042	**
Used improved planting materials (varieties)	54 (62.8%)	19 (42.2%)	47 (61.8%)	64 (68.8%)	33 (66.0%)	0.046	**
Land clearing and weed control	3 (3.49%)	4 (8.89%)	1 (1.32%)	3 (3.23%)	0 (0.00%)	0.149	
Awareness of pests and disease control	1 (1.16%)	2 (4.44%)	7 (9.21%)	4 (4.30%)	2 (4.00%)	0.188	
Use of planting space (1 m × 1 m)	25 (29.1%)	15 (33.3%)	26 (34.2%)	17 (18.3%)	11 (22.0%)	0.118	
Select a site with average soil fertility status	61 (70.9%)	29 (64.4%)	54 (71.1%)	57 (61.3%)	36 (72.0%)	0.527	
Select a site with excellent soil fertility status	23 (26.7%)	15 (33.3%)	20 (26.3%)	30 (32.3%)	9 (18.0%)	0.388	
Use at least in the last 2 seasons and approved cassava-improved seed	4.76 (3.80)	5.82 (3.91)	5.45 (3.93)	5.78 (4.14)	7.58 (4.19)	0.003	***
Socioeconomic characteristics							
Male household head	15 (17.4%)	33 (73.3%)	41 (53.9%)	55 (59.1%)	19 (38.0%)	0.000	***
Households farm characteristics							
Household size	7.07 (2.47)	9.89 (3.30)	9.53 (3.18)	7.82 (3.19)	8.48 (2.85)	0.000	***
Age of the household head	30.8 (6.09)	49.3 (7.98)	41.9 (5.29)	57.5 (6.74)	51.0 (11.1)	0.000	***
Education level							
Illiterate/no education	10 (11.6%)	4 (8.89%)	6 (7.89%)	20 (21.5%)	10 (20.0%)	0.052	***
Primary school level	14 (16.3%)	4 (8.89%)	59 (77.6%)	37 (39.8%)	30 (60.0%)	0.000	***
High school level	61 (70.9%)	37 (82.2%)	10 (13.2%)	35 (37.6%)	10 (20.0%)	0.000	***
University school level	1 (1.16%)	0 (0.00%)	1 (1.32%)	1 (1.08%)	0 (0.00%)	1.000	
Average years of education	8.08 (3.77)	8.51 (3.51)	5.59 (2.75)	5.53 (3.48)	4.68 (3.21)	0.000	***
Marital status/Married	70 (81.4%)	40 (88.9%)	67 (88.2%)	82 (88.2%)	39 (78.0%)	0.320	
Household heads occupations							
Stock breeder	0 (0.00%)	0 (0.00%)	1 (1.32%)	0 (0.00%)	0 (0.00%)	0.489	
Office worker	0 (0.00%)	0 (0.00%)	1 (1.32%)	1 (1.08%)	0 (0.00%)	0.869	
Trading	0 (0.00%)	1 (2.22%)	0 (0.00%)	0 (0.00%)	1 (2.00%)	0.073	*
Farming	84 (97.7%)	43 (95.6%)	73 (96.1%)	89 (95.7%)	46 (92.0%)	0.644	
Income							
Number of sources of revenue	1.62 (0.49)	1.67 (0.48)	1.50 (0.50)	1.46 (0.52)	1.48 (0.50)		
Average income < 100 USD	25 (29.1%)	10 (22.2%)	41 (53.9%)	45 (48.4%)	33 (66.0%)	0.085	*
Average income 100 USD–300 USD	45 (52.3%)	28 (62.2%)	24 (31.6%)	37 (39.8%)	15 (30.0%)		
Average income 300 USD–500 USD	9 (10.5%)	5 (11.1%)	7 (9.21%)	7 (7.53%)	2 (4.00%)		
Average income over 500 USD	7 (8.14%)	2 (4.44%)	4 (5.26%)	4 (4.30%)	0 (0.00%)		
Owened land	46 (53.5%)	36 (80.0%)	53 (69.7%)	55 (59.1%)	29 (58.0%)	0.022	**

Continued

Table 3. Continued.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	P overall	Sign
Land ownership							
Heritance land	38 (44.2%)	34 (75.6%)	51 (67.1%)	51 (54.8%)	26 (52.0%)	0.003	***
Buy land	19 (22.1%)	15 (33.3%)	19 (25.0%)	29 (31.2%)	13 (26.0%)	0.565	
Location land	2 (2.33%)	1 (2.22%)	1 (1.32%)	3 (3.23%)	2 (4.00%)	0.922	
Borrow land	18 (20.9%)	7 (15.6%)	19 (25.0%)	27 (29.0%)	17 (34.0%)	0.211	
Household wealth attributes							
Monthly Buying food sufficiency period	9.35 (3.37)	9.22 (3.31)	9.29 (3.92)	8.78 (3.87)	9.04 (3.59)	0.854	
Number of livestock species	2.67 (1.91)	2.82 (2.12)	2.58 (2.12)	2.58 (2.15)	2.70 (2.00)	0.968	
Cassava farming attribute							
Years of farming cassava	9.36 (8.58)	8.31 (7.40)	6.88 (5.82)	11.6 (7.19)	35.1 (10.6)	0.000	***
variete_actuelle_manioc	2.07 (0.97)	2.20 (0.92)	2.33 (1.18)	2.11 (0.91)	2.28 (0.97)	0.444	
Use cassava as cash and consumption crop	69 (80.2%)	39 (86.7%)	59 (77.6%)	72 (77.4%)	41 (82.0%)	0.730	
Use cassava as a cash crop	5 (5.81%)	1 (2.22%)	2 (2.63%)	1 (1.08%)	2 (4.00%)	0.450	
Use cassava as a consumption crop	12 (14.0%)	5 (11.1%)	15 (19.7%)	20 (21.5%)	7 (14.0%)	0.441	
Average hired casual labors	3.43 (1.96)	4.82 (3.08)	4.53 (2.54)	3.94 (2.56)	3.58 (2.43)	0.007	***
Average family labors	1.42 (1.51)	1.78 (1.52)	2.76 (1.59)	1.67 (1.48)	2.04 (1.60)	0.000	***
Adoption awareness of cassava practices							
Training in agriculture	20 (23.3%)	27 (60.0%)	40 (52.6%)	21 (22.6%)	15 (30.0%)	0.000	***
Training in animal breeding	7 (8.14%)	11 (24.4%)	9 (11.8%)	6 (6.45%)	5 (10.0%)	0.043	
Training in processing	0 (0.00%)	1 (2.22%)	1 (1.32%)	0 (0.00%)	0 (0.00%)	0.176	
Average number of hoeing tools	3.48 (3.60)	4.20 (4.32)	4.57 (4.79)	2.57 (2.64)	5.74 (6.31)	0.000	***
Improved variety selection criteria							
Hight root yield	72 (83.7%)	40 (88.9%)	63 (82.9%)	68 (73.1%)	41 (82.0%)	0.183	
High leaf yield	16 (18.6%)	28 (62.2%)	27 (35.5%)	23 (24.7%)	19 (38.0%)	0.000	***
Storage	6 (6.98%)	16 (35.6%)	14 (18.4%)	13 (14.0%)	7 (14.0%)	0.001	***
Diseases resistant	26 (30.2%)	23 (51.1%)	28 (36.8%)	25 (26.9%)	21 (42.0%)	0.043	
Last	28 (32.6%)	31 (68.9%)	40 (52.6%)	31 (33.3%)	19 (38.0%)	0.000	***
Source of improved seed							
Research	22 (25.6%)	11 (24.4%)	20 (26.3%)	19 (20.4%)	13 (26.0%)	0.897	
Friend	67 (77.9%)	34 (75.6%)	54 (71.1%)	70 (75.3%)	37 (74.0%)	0.902	
Parent	15 (17.4%)	28 (62.2%)	18 (23.7%)	24 (25.8%)	15 (30.0%)	0.000	***
Incidence of pests and diseases in the cassava field							
Incidence of rodents in the field	55 (64.0%)	16 (35.6%)	46 (60.5%)	57 (61.3%)	39 (78.0%)	0.001	***
CAD incidence %	1 (1.16%)	1 (2.22%)	0 (0.00%)	1 (1.08%)	1 (2.00%)	0.751	
CBB incidence %	2 (2.33%)	1 (2.22%)	3 (3.95%)	1 (1.08%)	1 (2.00%)	0.809	
CBSD incidence %	14 (16.3%)	6 (13.3%)	16 (21.1%)	15 (16.1%)	6 (12.0%)	0.694	
CMD incidence %	61 (70.9%)	35 (77.8%)	50 (65.8%)	66 (71.0%)	38 (76.0%)	0.626	
Disease incidence general %	8 (9.30%)	2 (4.44%)	7 (9.21%)	10 (10.8%)	4 (8.00%)	0.843	
Sample N (%)	86 (18.85%)	46 (13.08%)	76 (19.16%)	94 (19.46%)	50 (29.42%)	352 (100%)	

Significance codes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.



DESCRIPTIVE RESULTS FOR TANGANYIKA CLUSTERS

Table 3 presents five clusters identified through cluster analysis of farmers in the Tanganyika Province. These clusters are based

on various factors, including household characteristics, practices related to the adoption of improved technology, socioeconomic characteristics, modes of land acquisition, and techniques used in cassava cultivation. Significant differences were observed in

several areas: the number of improved cassava seeds utilized, the adoption of monoculture systems, the use of row cropping, seed utilization, and cultivation practices following fallowing periods. Specifically, the number of improved cassava seeds used in the last two seasons showed a significant difference ($P = 0.003$), as did the monoculture system ($P = 0.014$), the row cropping system ($P = 0.042$), the use of improved seeds ($P = 0.046$), and cultivation after fallow ($P = 0.068$). Additionally, the analysis revealed 11 distinct socioeconomic criteria that differentiate the clusters.

For cassava growing practices, three factors considerably separated the clusters. These three factors include the number of years of experience growing cassava, the number of family members utilized in each hectare of agriculture, and the number of workers per hectare. Concerning participation in awareness-raising campaigns on cassava cultivation practices, two factors distinguished the clusters: training in cassava cutting practices and the average number of hoeing tools owned. The clusters also differed in terms of variety selection criteria. The criteria for variety selection that distinctly distinguished the clusters included cassava leaf yield, taste, and storage conditions. The typological analysis of the Tanganyika Province revealed five farmer clusters across the districts, each exhibiting unique characteristics and specifics. These clusters are presented as follows:

Cluster 1. Young farmers are “very less demanding” in the selection of improved varieties

This group, accounting for approximately 19% of households, consists of younger, less demanding farmers who distinguish themselves from other clusters in several ways. The members of these clusters had the lowest average age, which was 30.8 years, compared to the other clusters. They also showed a relatively low level of adoption of improved cassava varieties, with an average of 4.8 varieties used per farmer. Moreover, this group displayed limited consideration of factors such as leaf redness, taste, and storage conditions when choosing cassava varieties for cultivation. The farmers in this group were predominantly women (83%), and the majority had completed secondary school (71%), with an average number of 8 years of study. Although they are moderately educated, they are less involved in agricultural training; only 23.3% of the household heads in this group said they had already received training in cassava cultivation. The heads of household in this group had approximately 9.3 years of experience cultivating cassava.

Cluster 2. Farmers are “very demanding” in the selection of improved varieties

This cluster comprises 13% of the sampled households in Tanganyika Province. Within this cluster, the predominant household heads are males, constituting 73% of the households. A substantial proportion of these households had a high level of education, 82% of whom had received formal education. The average age of the household heads in this group was 49 years, and they had an average of 8.3 years of experience in cassava cultivation. The participants had an average monthly income between 100 and 300 USD (62%), with an average household size of approximately 10 people. They own farmland (80%), most of which they acquired by inheritance (76%). The authors selected cassava varieties with high root yield (89%), good taste (69%), high leaf yield (62%), and disease resistance (51%).

Cluster 3. Less experienced and demanding farmers in a variety of selection

This group comprises 20% of the household samples. Most members of this cluster used improved varieties (62%) compared to members in Cluster 2. The cluster primarily consisted of male-headed households, accounting for 54%. The average age of the household heads in this group is approximately 41.9 years, and they have an average of 7 years of experience in cassava cultivation, which is comparatively lower than that of other clusters. The members of this cluster have a primary level of education

(78%), and they live on a monthly income of less than 100 USD with an average number of approximately 10 people per household. The majority (53%) had received training in cassava cultivation. The authors selected cassava varieties with high root yields (83%) and good taste (53%).

Cluster 4. Older farmers are “less demanding” in the selection of improved varieties

This group accounts for 19% of the farm household heads. Households in this cluster are mostly male-headed (59%), with an average of approximately eight people per household. The heads of household in this cluster are the oldest (57.5 years) and most highly educated (with an average of 8.5 years of education) compared to other groups. Farmers in this cluster do not use fertilizers because most leave their fields fallow before cultivation (83%). In addition, they are not very demanding when choosing improved cassava seeds. The primary concern of this cluster was root yield, with 73% of the participants prioritizing this gene when selecting cassava varieties. In contrast, a smaller proportion of the respondents considered attributes such as good taste (33%), disease resistance (27%), high leaf yield (25%), and long storage life (14%) when choosing which varieties to grow.

Cluster 5. More experienced farmers are somewhat demanding in the selection of improved varieties.

This particular group, which constitutes the largest percentage (29%) compared to other clusters, is mainly composed of households led by women (62%). The heads of household in this group used a relatively high number of improved cassava seeds, averaging approximately eight seeds in the last two seasons. This may be attributed to their extensive experience in cassava cultivation, which has an average of 35 years of experience. These plants tend to be quite selective concerning choosing improved cassava seeds, preferring varieties with high root yields (82%), high leaf yields (62%), and sometimes disease resistance (42%) and good taste (38%).

DESCRIPTIVE RESULTS FOR CLUSTERS IN SOUTHERN KIVU

Cluster 1, farmers who practice monocultures are less experienced, use more fertilizer, and are very demanding in terms of the choice of varieties

This group comprises 19% of households and distinguishes itself from other clusters by employing a significantly greater amount of fertilizer, approximately 71%, as indicated in Table 4. They tend to practice monoculture at a rate of 75%. Additionally, they often select land with average fertility, with this choice made by 82% of households in this cluster. Most farmers in this group are women, making up 61% of the total. Additionally, a significant majority, 66%, have not received formal education. The households in this group tend to be impoverished, with a monthly income of less than 100 USD, and an average of eight individuals per household. The average age of the heads of these households is 55.2 years, but they have less experience in cassava cultivation, averaging only 3.5 years, compared to those in other clusters. Moreover, the selection of cassava varieties for growth is more demanding. The authors selected varieties with high leaf yield (85%), long storage life (81%), disease resistance (61%), and good taste (61%). The heads of households in this group use cassava for both trade and consumption (92%).

Cluster 2, we found older farmers with more experience in cassava cultivation and predominantly male heads of household

Accounting for 18% of the farm households headed by men (62%), the oldest of whom (58.7 years on average) had more experience (39.6 years) in farming than did the other clusters. While the utilization of improved seeds seems relatively greater than that of other clusters, the adoption of improved technologies remains lower than that of the other cluster averages in this group.

Table 4. Summary descriptive table by "cluster" in South Kivu.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	P overall	Sign
	N=180	N=125	N=183	N=186	N=281		
Adoption of improved cassava production technologies							
After fallow	24 (13.3%)	36 (28.8%)	112 (61.2%)	54 (29.0%)	90 (32.0%)	0.000	***
After specific crop	55 (30.6%)	4 (3.20%)	9 (4.92%)	13 (6.99%)	32 (11.4%)	0.000	***
Use fertilizer	127 (70.6%)	31 (24.8%)	13 (7.10%)	35 (18.8%)	62 (22.1%)	0.000	***
Use tractor	26 (14.4%)	13 (10.4%)	21 (11.5%)	21 (11.3%)	29 (10.3%)	0.723	
Mono-cropping	135 (75.0%)	30 (24.0%)	31 (16.9%)	50 (26.9%)	90 (32.0%)	0.000	***
Line plant	5 (2.78%)	5 (4.00%)	5 (2.73%)	2 (1.08%)	9 (3.20%)	0.511	
Used improved seed	129 (71.7%)	106 (84.8%)	156 (85.2%)	149 (80.1%)	207 (73.7%)	0.002	***
Weed control	4 (2.22%)	1 (0.80%)	3 (1.64%)	4 (2.15%)	7 (2.49%)	0.896	
Pest control	5 (2.78%)	8 (6.40%)	11 (6.01%)	15 (8.06%)	23 (8.19%)	0.181	
Planting space	22 (12.2%)	30 (24.0%)	65 (35.5%)	40 (21.5%)	84 (29.9%)	0.000	***
Select a site with average soil fertility status	147 (81.7%)	75 (60.0%)	30 (16.4%)	128 (68.8%)	213 (75.8%)	0.000	***
Good soil fertility status	19 (10.6%)	48 (38.4%)	148 (80.9%)	49 (26.3%)	54 (19.2%)	0.000	***
Use at least in the last 2 seasons and approved cassava-improved seed	7.43 (3.78)	5.14 (3.34)	6.16 (4.23)	6.20 (4.03)	5.36 (3.99)	0.000	***
Socioeconomic characteristics							
Male household head	70 (38.9%)	78 (62.4%)	59 (32.2%)	51 (27.4%)	33 (11.7%)	0.000	***
Household size	8.18 (4.03)	8.72 (4.02)	9.31 (3.56)	8.42 (3.65)	8.32 (3.68)	0.031	**
Age of the household head	55.2 (11.0)	58.7 (12.4)	37.5 (9.08)	44.4 (9.10)	29.8 (7.30)	0.000	***
Education level							
Illiterate/no education	118 (65.6%)	42 (33.6%)	11 (6.01%)	118 (63.4%)	28 (9.96%)	0.000	***
Primary school level	22 (12.2%)	48 (38.4%)	40 (21.9%)	51 (27.4%)	68 (24.2%)	0.000	***
High school level	39 (21.7%)	34 (27.2%)	122 (66.7%)	16 (8.60%)	173 (61.6%)	0.000	***
University school level	1 (0.56%)	1 (0.80%)	10 (5.46%)	10 (5.46%)	12 (4.27%)	0.002	***
Average years of education	3.29 (3.64)	4.82 (4.00)	8.88 (3.90)	2.70 (2.80)	8.27 (3.98)	0.000	***
Marital status/Married	164 (91.1%)	106 (84.8%)	136 (74.3%)	122 (65.6%)	205 (73.0%)	0.000	***
Household heads occupations							
Stock breeder	1 (0.56%)	0 (0.00%)	2 (1.09%)	0 (0.00%)	0 (0.00%)	0.172	
Officer worker	2 (1.11%)	2 (1.60%)	9 (4.92%)	0 (0.00%)	11 (3.91%)	0.172	
Trading	1 (0.56%)	1 (0.80%)	4 (2.19%)	2 (1.08%)	3 (1.07%)	0.741	
Farming	176 (97.8%)	121 (96.8%)	165 (90.2%)	181 (97.3%)	259 (92.2%)	0.002	***
Income							
Number of sources of revenue	1.69 (0.56)	1.48 (0.58)	1.79 (0.57)	1.52 (0.60)	1.65 (0.64)	0.000	***
Average income < 100 USD	114 (63.3%)	43 (34.4%)	59 (32.2%)	111 (59.7%)	166 (59.1%)	0.000	***
Average income 100 USD–300 USD	41 (22.8%)	52 (41.6%)	76 (41.5%)	53 (28.5%)	73 (26.0%)		
Average income 300 USD–500 USD	14 (7.78%)	17 (13.6%)	29 (15.8%)	17 (9.14%)	29 (10.3%)		
Average income over 500 USD	11 (6.11%)	13 (10.4%)	19 (10.4%)	5 (2.69%)	13 (4.63%)		
Total land size (Ha)	164 (91.1%)	94 (75.2%)	119 (65.0%)	130 (69.9%)	210 (74.7%)	0.000	***
Land ownership							
Heritage land	150 (83.3%)	80 (64.0%)	106 (57.9%)	121 (65.1%)	191 (68.0%)	0.000	***

Continued

Table 4. Continued.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	P overall	Sign
Buy land	144 (80.0%)	47 (37.6%)	67 (36.6%)	59 (31.7%)	111 (39.5%)	0.000	***
Location land	18 (10.0%)	1 (0.80%)	13 (7.10%)	7 (3.76%)	11 (3.91%)	0.003	***
Borrow land	20 (11.1%)	18 (14.4%)	35 (19.1%)	43 (23.1%)	48 (17.1%)	0.034	**
Farmers casual labors	2.87 (2.63)	2.80 (3.16)	2.78 (2.38)	2.53 (2.71)	.92 (2.13)	0.000	***
Family full labors	0.96 (1.46)	0.39 (0.93)	0.63 (1.29)	0.56 (1.26)	0.69 (1.24)	0.002	***
Household wealth attributes							
Monthly buying food sufficiency period	8.67 (3.69)	9.98 (2.84)	9.58 (3.08)	9.97 (2.86)	9.19 (3.56)	0.000	***
Number of livestock species	2.14 (1.74)	2.24 (1.82)	2.61 (1.84)	2.72 (1.82)	2.67 (1.97)	0.006	***
Cassava farming attribute							
Years of farming cassava	3.47 (4.78)	39.6 (12.0)	16.8 (10.0)	18.0 (8.77)	7.39 (6.76)	0.000	***
Use cassava as cash and consumption crop	166 (92.2%)	92 (73.6%)	149 (81.4%)	143 (76.9%)	210 (74.7%)	0.000	***
Use cassava as a cash crop	2 (1.11%)	4 (3.20%)	6 (3.28%)	4 (2.15%)	6 (2.14%)	0.617	
Use cassava as a consumption crop	12 (6.67%)	29 (23.2%)	28 (15.3%)	39 (21.0%)	65 (23.1%)	0.000	***
Average hired casual labors	2.87 (2.63)	2.80 (3.16)	2.78 (2.38)	2.53 (2.71)	1.92 (2.13)	0.000	***
Average family labors	0.96 (1.46)	0.39 (0.93)	0.63 (1.29)	0.56 (1.26)	0.69 (1.24)	0.002	***
Adoption awareness of cassava practices							
Agriculture train	31 (17.2%)	33 (26.4%)	95 (51.9%)	36 (19.4%)	66 (23.5%)	0.000	***
Animal trail	3 (1.67%)	1 (0.80%)	12 (6.56%)	0 (0.00%)	10 (3.56%)	0.001	***
Processing training	2 (1.11%)	4 (3.20%)	11 (6.01%)	0 (0.00%)	6 (2.14%)	0.002	***
variete_actuelle_maniocnumberca	1.86 (0.77)	1.94 (0.69)	2.00 (0.82)	1.94 (0.85)	1.89 (0.72)	0.459	
Improved variety selection criteria							
High root yield	153 (85.0%)	78 (62.4%)	128 (69.9%)	142 (76.3%)	217 (77.2%)	0.000	***
High leaf yield	74 (41.1%)	46 (36.8%)	54 (29.5%)	54 (29.0%)	85 (30.2%)	0.050	**
Storage	228 (81.1%)	18 (14.4%)	28 (15.3%)	31 (16.7%)	53 (18.9%)	0.000	***
Disease resistant	111 (61.7%)	38 (30.4%)	92 (50.3%)	46 (24.7%)	95 (33.8%)	0.000	***
Taste	110 (61.1%)	28 (22.4%)	58 (31.7%)	50 (26.9%)	98 (34.9%)	0.000	***
Source of improved seed							
Research	63 (35.0%)	35 (28.0%)	81 (44.3%)	69 (37.1%)	84 (29.9%)	0.010	**
Friend	108 (60.0%)	80 (64.0%)	114 (62.3%)	120 (64.5%)	185 (65.8%)	0.768	
Parent	79 (43.9%)	26 (20.8%)	51 (27.9%)	49 (26.3%)	87 (31.0%)	0.000	***
Incidence of pests and diseases in the cassava field							
Incidence of rodents in the field	44 (24.4%)	112 (89.6%)	136 (74.3%)	156 (83.9%)	179 (63.7%)		
CAD incidence %	2 (1.11%)	0 (0.00%)	5 (2.73%)	1 (0.54%)	7 (2.49%)	0.168	
CBB incidence %	3 (1.67%)	2 (1.60%)	12 (6.56%)	9 (4.84%)	13 (4.63%)	0.092	*
CBSD incidence %	20 (11.1%)	19 (15.2%)	37 (20.2%)	25 (13.4%)	50 (17.8%)	0.121	
CMD incidence %	109 (60.6%)	91 (72.8%)	110 (60.1%)	131 (70.4%)	176 (62.6%)	0.044	**
Disease incidence general %	46 (25.6%)	13 (10.4%)	19 (10.4%)	20 (10.8%)	35 (12.5%)	0.000	***
Sample N (%)	182 (18.85%)	126 (13.08%)	185 (19.16%)	188 (19.46%)	284 (29.42%)	965 (100%)	

SD: standard deviation. The data were collected from selected smallholder farmers in the Eastern DRC in South Kivu and Tanganyika Provinces; the *P*-value represents one-way ANOVA (equality of group means). Significance codes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Additionally, these households demonstrate low participation in training programs, which further restricts their ability to adopt new technologies. When selecting varieties, farmers prioritize root yield (62%), while factors such as leaf yield, disease resistance, taste, and storage conditions are considered by a smaller percentage of them.

Cluster 3 was characterized by farmers practicing fallow systems and trained in cassava cultivation

This cluster comprises 19% of households and differs from other clusters in that its members use almost no fertilizer because they select land with excellent fertility (81%). In addition, they adopt a system of fallowing before cultivation and make greater use of improved seeds than farmers in other clusters make fallow. More than half of the heads of households in this group (52%) had participated in at least one training program on cassava cultivation, which was not true for the other clusters. The authors selected varieties that exhibited both high root yield (70%) and disease resistance (50%).

Cluster 4 comprises 19% of the households, primarily women, with an average age of 44.4 years

Despite being less educated and having a lower participation rate in agricultural training programs, they have high experience. Despite this, these farms mainly utilize improved seeds, indicating that capacity building could be an effective strategy for enhancing their production systems. Cluster 5 consists of a higher number of young farmers, predominantly women (88%), with an average age of 29.8 years, and they cultivate a larger variety of improved plant types. These farmers typically choose land with average fertility that yields high root production (Fig. 5).

DETERMINANTS OF ADOPTION OF IMPROVED CASSAVA PLANTING MATERIALS AND FERTILIZER

Table 5 reveals several factors that positively affect the adoption of improved cassava seeds among farmers in South Kivu, with

implications for agricultural planning and intervention. The years of cassava farming experience are notably influential in Cluster 5, where each additional year raises the likelihood of adoption by 15.1% ($P < 0.05$). Education, however, plays a crucial role: primary education significantly increases the likelihood of adoption in Cluster 1 by 17.4% ($P < 0.10$), underscoring the role of education in technology adoption. The land area also emerges as a major factor; the total land area cultivated significantly raises adoption in Cluster 4 by 46.9% ($P < 0.01$), suggesting that larger farm sizes provide more opportunities for technology use. Furthermore, training programs are highly effective in Cluster 5, boosting the likelihood of adoption by 18.2% ($P < 0.10$), and emphasizing the importance of farmer education and extension services.

Table 6 presents a more complex set of factors affecting the adoption of improved seeds in Tanganyika province. However, marital status in Cluster 5 stands out, with being married, increasing the probability of adopting improved seeds by 0.95% ($P < 0.05$), suggesting the importance of shared decision-making in household farming practices. University education is significant in Cluster 5, where it increases adoption likelihood by 20.1% ($P < 0.10$), indicating that higher education can lead to a greater understanding and acceptance of agricultural innovations. Total land area cultivated in Cluster 1 is another critical factor, enhancing adoption probability by 79.6% ($P < 0.01$), reflecting the benefits of having more land to implement new practices. Livestock ownership in Cluster 1 also contributes positively, raising adoption by 26.8% ($P < 0.05$), which suggests that livestock assets can facilitate investments in improved seeds. Additionally, agricultural training remains crucial, increasing adoption by 14.3% ($P < 0.10$) in the overall model, highlighting the value of training programs for successful technology uptake.

Table 7 focuses on factors that influence fertilizer adoption among farmers in South Kivu, with gender playing a significant role. Male farmers in clusters 1 and 5 are more likely to adopt fertilizer, with increases of 18.0% ($P < 0.10$) and 14.9% ($P < 0.05$), respectively, likely due to greater resource access and decision-making power. Marital status has a positive effect in Cluster 4, where being

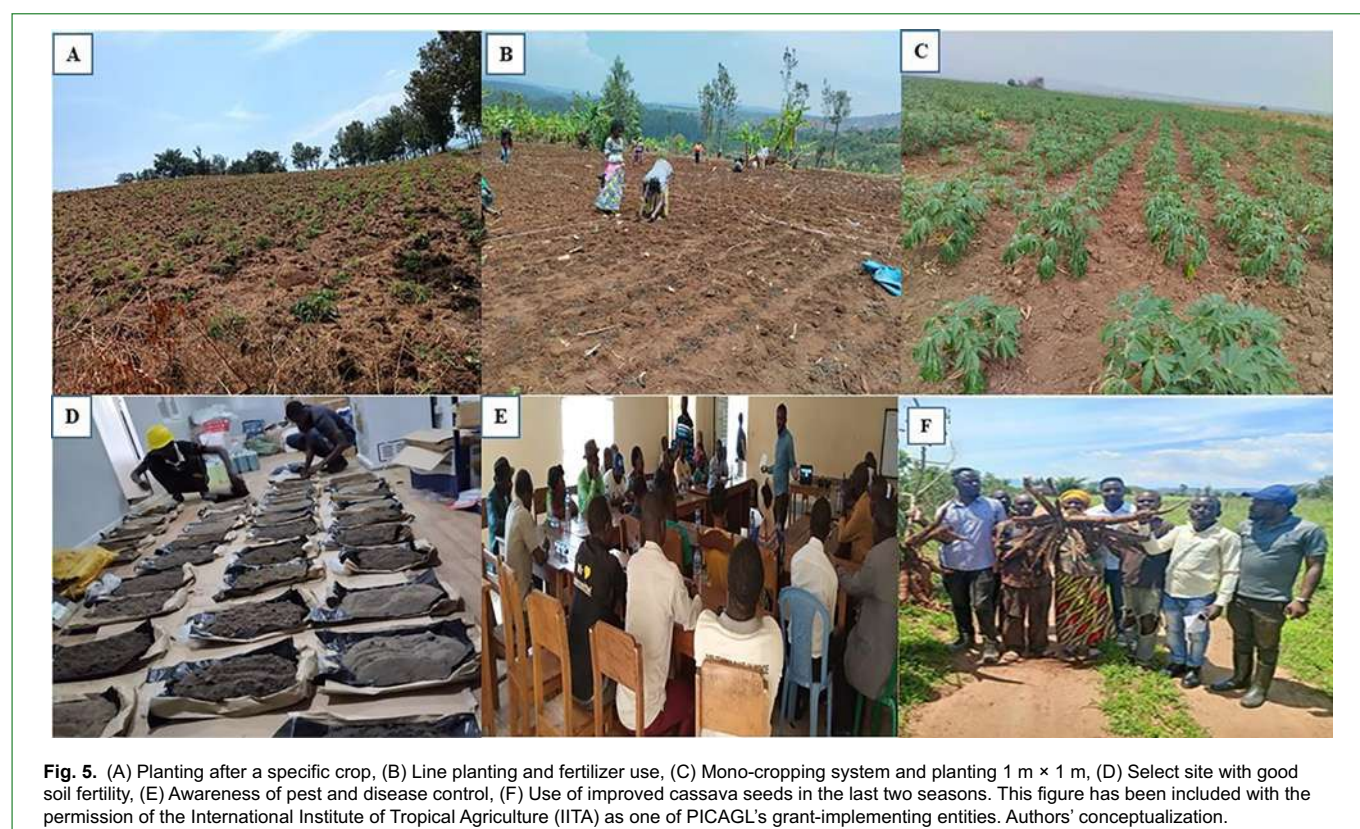


Table 5. Estimation of logit model for determinants of adoption of cassava-improved seed in South Kivu.

Variables	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5		All Cluster South Kivu	
	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx
Gender	0.376 (0.535)	0.0707 (0.101)	-0.512 (0.426)	-0.0995 (0.0827)	0.581 (0.407)	0.122 (0.0840)	-0.0231 (0.330)	-0.00493 (0.0705)	0.273 (0.303)	0.0529 (0.0581)	0.141 (0.157)	0.0288 (0.0321)
Geographic location	-0.0159 (0.0170)	-0.00295 (0.00316)	0.0223 (0.0143)	0.00428 (0.00272)	0.00434 (0.0149)	0.000914 (0.00312)	0.0106 (0.0118)	0.00225 (0.00250)	0.0102 (0.0109)	0.00200 (0.00212)	0.00762 (0.00546)	0.00156 (0.00112)
Cassava farming experience	-0.649 (0.536)	-0.113 (0.0866)	0.201 (0.473)	0.0397 (0.0954)	-0.0804 (0.421)	-0.0168 (0.0872)	0.308 (0.389)	0.0679 (0.0880)	0.714** (0.326)	0.151** (0.0731)	0.227 (0.171)	0.0477 (0.0367)
Marital status	0.00265 (0.0188)	0.000493 (0.00348)	0.00212 (0.0135)	0.000408 (0.00259)	0.0174 (0.0129)	0.00366 (0.00270)	-0.0285** (0.0118)	-0.00608** (0.00252)	0.00785 (0.00988)	0.00153 (0.00192)	0.00240 (0.00522)	0.000492 (0.00107)
Age	0.734 (0.591)	0.126 (0.0929)	-0.517 (0.491)	-0.105 (0.104)	0.449 (0.488)	0.0907 (0.0936)	-0.745* (0.438)	-0.170 (0.105)	-0.00900 (0.369)	-0.00176 (0.0722)	-0.0514 (0.191)	-0.0106 (0.0395)
Primary education	0.986 (0.619)	0.174* (0.101)	0.482 (0.504)	0.0909 (0.0923)	0.481 (0.496)	0.0987 (0.0984)	-0.637* (0.382)	-0.138* (0.0834)	0.263 (0.372)	0.0505 (0.0702)	0.237 (0.189)	0.0481 (0.0379)
High school education	—	—	—	—	0.0859 (0.877)	0.0178 (0.179)	—	—	1.088 (1.177)	0.160 (0.119)	0.675 (0.548)	0.118 (0.0791)
University	0.0264 (0.524)	0.00491 (0.0978)	0.360 (0.421)	0.0716 (0.0859)	-0.231 (0.384)	-0.0477 (0.0777)	0.218 (0.368)	0.0474 (0.0816)	0.103 (0.324)	0.0204 (0.0650)	0.0453 (0.159)	0.00933 (0.0329)
Land ownership	0.00460 (0.0658)	0.000854 (0.0122)	0.0729 (0.0538)	0.0140 (0.0103)	0.0521 (0.0528)	0.0110 (0.0111)	-0.0296 (0.0409)	-0.00631 (0.00873)	0.0210 (0.0351)	0.00410 (0.00684)	0.0222 (0.0191)	0.00454 (0.00391)
Household size	-0.422 (1.439)	-0.0783 (0.267)	0.561 (0.881)	0.108 (0.169)	-0.0165 (0.950)	-0.00346 (0.200)	0.400 (1.173)	0.0852 (0.250)	-0.261 (0.718)	-0.0509 (0.140)	-0.155 (0.393)	-0.0318 (0.0805)
Cassava land area	0.297 (1.312)	0.0551 (0.243)	-0.563 (0.745)	-0.108 (0.143)	0.0722 (0.600)	0.0152 (0.126)	0.0827 (1.035)	0.0176 (0.221)	0.242 (0.619)	0.0471 (0.121)	0.229 (0.322)	0.0469 (0.0659)
Total land area cultivated	1.467* (0.879)	0.337 (0.210)	-0.949 (0.848)	-0.144 (0.0969)	0.473 (0.477)	0.106 (0.112)	2.047*** (0.730)	0.469*** (0.132)	-0.327 (0.465)	-0.0594 (0.0786)	0.413* (0.244)	0.0906 (0.0564)
Involving in farming activity	-0.147 (0.285)	-0.0272 (0.0529)	0.400 (0.268)	0.0769 (0.0508)	-0.550*** (0.212)	-0.116*** (0.0444)	0.249 (0.190)	0.0531 (0.0404)	0.0289 (0.175)	0.00563 (0.0342)	-0.0334 (0.0875)	-0.00685 (0.0179)
Income	-0.0155 (0.126)	-0.00288 (0.0233)	-0.0356 (0.111)	-0.00685 (0.0214)	-0.0843 (0.0945)	-0.0177 (0.0199)	-0.164** (0.0816)	-0.0350** (0.0173)	-0.0768 (0.0724)	-0.0150 (0.0141)	-0.0736* (0.0385)	-0.0151* (0.00788)
Number of livestock	-1.080** (0.523)	-0.227* (0.117)	0.260 (0.472)	0.0487 (0.0860)	-0.0353 (0.399)	-0.00745 (0.0845)	-0.187 (0.382)	-0.0406 (0.0846)	-0.448 (0.348)	-0.0916 (0.0739)	-0.269 (0.171)	-0.0566 (0.0368)
Training in agriculture	—	—	-1.530 (1.209)	-0.356 (0.286)	0.711 (1.315)	0.128 (0.194)	—	—	1.328 (1.156)	0.182* (0.0978)	0.726 (0.592)	0.125 (0.0826)
Mean dependent var	0.739		0.713		0.692		0.683		0.730		0.714	
Number of obs	119		157		169		227		285		967	
Prob > chi2	0.016		0.005		0.019		0.000		0.000		0.000	
SD dependent var	0.441		0.454		0.463		0.466		0.445		0.452	
Chi-square	27.669		32.658		29.822		39.585		57.375		165.338	
Akaike crit. (AIC)	155.806		202.014		228.062		293.421		355.342		1181.129	

Significance codes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 6. Estimation of logit model for determinants of adoption of improved cassava seed in Tanganyika and all.

Use cassava-improved seed	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5		All Cluster Tanganyika		All Cluster (South Kivu and Tanganyika)	
	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx
Gender	88.74 (0)	1 (0)	1.914 (1.539)	0.376 (0.301)	-1.539 (0.996)	-0.309* (0.172)	0.0818 (0.508)	0.0197 (0.123)	-0.489 (0.470)	-0.121 (0.115)	-0.212 (0.261)	-0.0507 (0.0618)	-0.0420 (0.131)	-0.00910 (0.0284)
Geographic location	1.839 (0)	0 (0)	0.0867 (0.0690)	0.0156 (0.0117)	0.0289 (0.0390)	0.00635 (0.00851)	0.0229 (0.0227)	0.00551 (0.00545)	-0.042** (0.0196)	-0.0106** (0.00489)	-0.00326 (0.0103)	-0.00078 (0.00247)	0.00654 (0.00470)	0.00142 (0.00102)
Cassava farming experience	—	—	-1.896 (1.692)	-0.236* (0.134)	-1.734 (1.276)	-0.281** (0.132)	0.568 (0.628)	0.140 (0.155)	0.0338 (0.580)	0.00844 (0.145)	-0.271 (0.323)	-0.0637 (0.0740)	0.125 (0.149)	0.0275 (0.0330)
Marital status	0.877 (0)	0 (0)	0.00890 (0.0318)	0.00160 (0.00564)	0.0127 (0.0299)	0.00279 (0.00656)	-0.00694 (0.0188)	-0.00167 (0.00453)	0.0382** (0.0165)	0.00954** (0.00411)	0.0135 (0.00861)	0.00323 (0.00206)	0.00304 (0.00431)	0.000659 (0.000934)
Age	-94.38 (0)	-1 (0)	-2.304 (2.131)	-0.401 (0.336)	1.023 (1.050)	0.217 (0.208)	-1.014 (0.729)	-0.246 (0.173)	-1.274* (0.667)	-0.307** (0.150)	-0.371 (0.354)	-0.0894 (0.0855)	-0.187 (0.159)	-0.0412 (0.0353)
Primary education	-161.0 (0)	-1 (0)	-5.143 (3.242)	-0.82*** (0.263)	1.589 (1.192)	0.324 (0.212)	-0.452 (0.675)	-0.108 (0.161)	-1.065 (0.673)	-0.260* (0.157)	-0.215 (0.372)	-0.0516 (0.0895)	0.0855 (0.162)	0.0185 (0.0349)
High school education	—	—	—	—	—	—	—	—	—	—	—	—	0.804 (0.532)	0.147* (0.0776)
University	-0.176 (0)	0 (0)	-1.195 (1.102)	-0.189 (0.150)	0.602 (0.643)	0.134 (0.144)	-0.152 (0.478)	-0.0365 (0.114)	0.817* (0.455)	0.201* (0.109)	0.0951 (0.230)	0.0229 (0.0554)	0.138 (0.127)	0.0303 (0.0281)
Land ownership	-12.02 (0)	0 (0)	-0.293 (0.200)	-0.0526 (0.0340)	0.0605 (0.102)	0.0133 (0.0223)	0.0577 (0.0768)	0.0139 (0.0184)	0.0141 (0.0640)	0.00352 (0.0160)	-0.0205 (0.0357)	-0.00492 (0.00858)	0.0112 (0.0164)	0.00244 (0.00356)
Household size	423.4 (0)	0 (0)	-18.12** (9.145)	-3.261** (1.590)	0.440 (1.892)	0.0968 (0.416)	-0.448 (1.256)	-0.108 (0.302)	0.448 (0.856)	0.112 (0.214)	-0.491 (0.523)	-0.118 (0.126)	-0.238 (0.303)	-0.0516 (0.0656)
Cassava land area	-394.5 (0)	0 (0)	12.46 (8.321)	2.242 (1.469)	-1.048 (1.696)	-0.231 (0.374)	-0.0646 (1.038)	-0.0156 (0.250)	-0.496 (0.560)	-0.124 (0.140)	-0.0415 (0.402)	-0.00996 (0.0964)	0.0851 (0.243)	0.0184 (0.0526)
Total land area cultivated	—	—	6.025** (2.540)	0.796*** (0.0983)	-0.196 (2.213)	-0.0415 (0.452)	—	—	-0.855 (0.833)	-0.201 (0.177)	0.325 (0.468)	0.0797 (0.116)	0.334 (0.209)	0.0760 (0.0493)
Involving in farming activity	53.92 (0)	0 (0)	-0.873 (0.709)	-0.157 (0.125)	-0.168 (0.442)	-0.0370 (0.0969)	0.245 (0.286)	0.0589 (0.0686)	0.133 (0.287)	0.0331 (0.0716)	0.0463 (0.145)	0.0111 (0.0347)	0.0318 (0.0726)	0.00690 (0.0157)
Income	6.029 (0)	0 (0)	1.185** (0.559)	0.213** (0.0896)	0.279 (0.182)	0.0614 (0.0394)	0.0434 (0.114)	0.0104 (0.0274)	-0.0659 (0.108)	-0.0165 (0.0270)	0.120** (0.0564)	0.0289** (0.0135)	-0.0110 (0.0311)	-0.00239 (0.00674)

Continued

Table 6. Continued.

Use cassava-improved seed Variables	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5		All Cluster Tanganyika		All Cluster (South Kivu and Tanganyika)	
	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx	Estimated	Mfx
Number of livestock	—	—	2.042 (1.432)	0.268** (0.135)	0.694 (0.719)	0.149 (0.149)	-0.657 (0.483)	-0.159 (0.117)	0.612 (0.452)	0.151 (0.109)	0.196 (0.243)	0.0467 (0.0574)	-0.146 (0.137)	-0.0321 (0.0304)
Training in agriculture	—	—	—	—	—	—	—	—	—	—	—	—	0.784 (0.580)	0.143* (0.0853)
Mean dependent var	0.688		0.673		0.629		0.591		0.526		0.598		0.684	
Number of obs	16		49		62		93		114		346		1317	
Prob > chi2	.		0.790		0.743		0.827		0.394		0.055		0.000	
SD dependent var	0.479		0.474		0.487		0.494		0.502		0.491		0.465	
Chi-square	.		9.608		10.263		8.248		14.771		23.369		170.397	
Akaike crit. (AIC)	0.000		65.386		97.512		145.498		167.266		482.278		1667.658	

Significance codes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 7. Estimation of logit model for determinants of adoption of Fertilizer in South Kivu.

Use Fertilizer	Cluster I			Cluster II			Cluster III			Cluster IV			Cluster V			All Cluster South Kivu		
	Estimated	Mfx		Estimated	Mfx		Estimated	Mfx		Estimated	Mfx		Estimated	Mfx		Estimated	Mfx	
Gender	1.046* (0.578)	0.180* (0.0933)		1.037** (0.503)	0.145** (0.0704)		0.492 (0.541)	0.0591 (0.0655)		-0.0837 (0.342)	-0.0182 (0.0741)		0.672** (0.325)	0.149** (0.0718)		0.473** (0.170)	0.0902*** (0.0324)	
Geographic location	-0.0363* (0.0213)	-0.00648* (0.00369)		-0.0652*** (0.0195)	-0.00872*** (0.00235)		-0.0675*** (0.0229)	-0.00803*** (0.00256)		-0.0578*** (0.0141)	-0.0126*** (0.00295)		-0.0543*** (0.0131)	-0.0120*** (0.00278)		-0.0532*** (0.00681)	-0.0101*** (0.00123)	
Cassava farming experience	-0.927* (0.518)	-0.180* (0.105)		0.680 (0.629)	0.0803 (0.0645)		0.151 (0.589)	0.0175 (0.0664)		-0.360 (0.412)	-0.0812 (0.0955)		-0.0437 (0.355)	-0.00968 (0.0789)		-0.198 (0.192)	-0.0386 (0.0382)	
Marital status	0.0150 (0.0173)	0.00268 (0.00310)		0.0189 (0.0152)	0.00253 (0.00203)		0.00866 (0.0160)	0.00103 (0.00190)		0.0239** (0.0119)	0.00520** (0.00258)		0.0148 (0.00969)	0.00326 (0.00215)		0.0169*** (0.00556)	0.00321*** (0.00106)	
Age	0.253 (0.591)	0.0462 (0.111)		-0.785 (0.570)	-0.0927 (0.0601)		-0.954* (0.563)	-0.101* (0.0543)		-0.0946 (0.432)	-0.0203 (0.0918)		-0.230 (0.372)	-0.0497 (0.0786)		-0.422** (0.200)	-0.0758** (0.0339)	
Primary education	-0.560 (0.606)	-0.0964 (0.0995)		-1.552*** (0.588)	-0.195*** (0.0697)		-1.772*** (0.697)	-0.193*** (0.0697)		-1.020*** (0.390)	-0.212*** (0.0754)		-0.761* (0.400)	-0.161** (0.0796)		-1.045*** (0.205)	-0.187*** (0.0339)	
High school education	—	—		—	—		—	—		—	—		1.829 (1.197)	0.426* (0.228)		-1.343** (0.570)	-0.177*** (0.0462)	
University	-0.0534 (0.517)	-0.00959 (0.0933)		0.105 (0.506)	0.0138 (0.0659)		0.557 (0.501)	0.0615 (0.0515)		-0.194 (0.383)	-0.0430 (0.0860)		0.00641 (0.344)	0.00141 (0.0757)		0.0427 (0.176)	0.00807 (0.0331)	
Land ownership	-0.0820 (0.0634)	-0.0146 (0.0112)		0.00203 (0.0616)	0.000272 (0.00824)		0.0880 (0.0650)	0.0105 (0.00759)		-0.0148 (0.0422)	-0.00322 (0.00917)		0.0134 (0.0350)	0.00295 (0.00772)		-0.0131 (0.0204)	-0.00250 (0.00387)	
Household size	-0.0845 (1.746)	-0.0151 (0.312)		0.980 (1.079)	0.131 (0.144)		3.716* (1.934)	0.442** (0.210)		-1.035 (1.173)	-0.225 (0.255)		-0.530 (0.899)	-0.117 (0.198)		0.311 (0.394)	0.0590 (0.0747)	
Cassava land area	-0.616 (1.676)	-0.110 (0.298)		-0.483 (1.039)	-0.0647 (0.139)		-1.862 (1.651)	-0.222 (0.185)		1.784* (1.052)	0.388* (0.229)		1.000 (0.761)	0.221 (0.168)		0.201 (0.317)	0.0382 (0.0602)	
Total land area cultivated	—	—		-1.002 (0.919)	-0.176 (0.197)		-0.587 (0.669)	-0.0825 (0.107)		-0.169 (0.701)	-0.0379 (0.161)		—	—		-0.0332 (0.283)	-0.00634 (0.0545)	
Involving in farming activity	-0.106 (0.325)	-0.0190 (0.0579)		-0.438 (0.327)	-0.0586 (0.0424)		-0.484* (0.285)	-0.0576* (0.0332)		0.0524 (0.194)	0.0114 (0.0422)		-0.328* (0.193)	-0.0724* (0.0424)		-0.203** (0.0979)	-0.0385** (0.0185)	
Income	0.0540 (0.129)	0.00964 (0.0231)		-0.0712 (0.135)	-0.00953 (0.0180)		-0.322** (0.134)	-0.0383** (0.0159)		-0.0590 (0.0840)	-0.0128 (0.0182)		-0.119 (0.0783)	-0.0262 (0.0172)		-0.0992** (0.0419)	-0.0188** (0.00792)	
Number of livestock	0.483 (0.525)	0.0922 (0.106)		0.387 (0.535)	0.0546 (0.0789)		0.441 (0.536)	0.0564 (0.0726)		-0.251 (0.419)	-0.0531 (0.0860)		-0.446 (0.392)	-0.0942 (0.0785)		-0.0155 (0.191)	-0.00293 (0.0362)	
Training in agriculture	—	—		0.00992 (1.402)	0.00133 (0.189)		—	—		—	—		0.0984 (1.220)	0.0220 (0.277)		0.337 (0.589)	0.0689 (0.128)	
Mean dependent var	0.261			0.223			0.204			0.352			0.347			0.281		
Number of obs	115			157			157			227			265			967		
Prob > chi2	0.017			0.000			0.000			0.000			0.000			0.000		
SD dependent var	0.441			0.418			0.404			0.479			0.477			0.450		
Chi-square	26.080			41.014			43.877			42.637			48.971			212.655		
Akaike crit. (AIC)	144.096			165.298			154.867			282.113			325.011			1058.698		

Significance codes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

married raises the probability of adoption by 0.52% ($P < 0.05$), reflecting the benefits of spousal collaboration. The land area dedicated to cassava cultivation is highly impactful in Cluster 4, where each additional hectare increases the likelihood of fertilizer use by 38.8% ($P < 0.10$), showing the economic benefits of higher productivity. While the effects of income are varied, a positive income effect highlights that financial resources can facilitate the use of fertilizers. Overall, factors such as education, gender, and land resources play crucial roles in fertilizer adoption. Additionally, agricultural training consistently has a positive impact, increasing adoption rates by 6.9% in the overall model. This emphasizes the importance of targeted education and resource allocation in improving fertilizer use and overall productivity.

The variance inflation factor (VIF) analysis in Table 8 shows no significant multicollinearity among individual predictors across Tables 5–7. Predictor VIF values in Table 5 range from 1.08 to 1.44, in Table 6 from 1.05 to 1.40, and in Table 7 from 1.04 to 1.34, all remaining well below the threshold of 5. High VIF values for constants do not affect model reliability, confirming the independence of predictor variables. The logistic regression models used to study the adoption of improved cassava seeds and fertilizers demonstrate strong model fit and robustness. Significant chi-square test results with P -values at or below 0.05 highlight the importance of included variables. The Akaike information criterion (AIC) values indicate a balanced model that avoids excessive complexity, while the standard deviation of the dependent variable reflects variability in adoption probabilities. Tables 5 and 6 support model adequacies with significant chi-square, P -values, and appropriate AIC values, emphasizing explanatory power without overfitting. Table 7, focused on fertilizer adoption in South Kivu, similarly shows strong performance with AIC values and meaningful standard deviations. Overall, these results validate the logistic regression models as effective for analyzing factors influencing the adoption of improved agricultural practices.

Discussion

This study found that differences among cassava farmers are influenced by factors such as years of experience, marital status, gender, age, land ownership, and land size. Specifically, the age of the household head affected the likelihood of adopting fertilizer in Cluster 1, while gender had an impact in Cluster 5. In addition, younger farmers are more likely to adopt innovations than older farmers are. The average age of the household heads in this study was 43 years, and the household head had 14 years of experience in cassava farming. As found in Malawi and Tanzania by Gebrekidan *et al.* (2020) and Makate and Mango (2017), farmer age is the key factor that helps to explain recent farmers' forced labor and risk perception in farming activities. These findings were also observed in previous studies in the Eastern region of the DRC (Mubalama *et al.*, 2019) on the determinants of adoption and farmers' preferences for cassava varieties, where he illustrated that 67% of the farmers had between 11 and 20 years of experience. Most cassava farmers are in their prime productive years, enabling them to actively adopt modern agricultural production technologies. Furthermore, the number of years spent farming increases the likelihood of accepting cassava-improved seeds in cluster 5. According to Makate and Mango (2017), farmers attend to various household activities and adopt agricultural innovation to support their sex-specific roles in farming activities and the decisions they make in their households. Marital status and gender male-headed households were more likely to intensify fertilizer use than female-headed households were. These results are like those found in India, Nigeria, and Rwanda by other scholars (Goswami *et al.*, 2014; Kilwinger *et al.*, 2021; Victor Uzochukwu *et al.*, 2021a). In the South Kivu and Tanganyika provinces, male-headed households have access to resources such as productive land (Martey *et al.*, 2013; Nwaobiala, 2017; Sarker *et al.*, 2021b). According to the findings of Joshua Udoh and Titus Omonona (2008), in Nigeria, no accessibility of production

resources limits female-headed households concerning fertilizer use, implying that male household heads are more likely to adopt improved cassava varieties than their female counterparts are. The area under cultivation was negatively related to fertilizer adoption in Cluster 1 and Cluster 3. The results imply that as farm size increases, farmers are more likely not to adopt fertilizer. These latter results follow the findings of Ayoola and Makinde (2007) and Lambrecht *et al.* (2016) in East Africa and Ghana on the adoption of fertilizer constraints. In 2016, they demonstrated that in northern Ghana and the Eastern DRC, the adoption of fertilizer was low, especially among smallholder farmers, largely due to financial constraints. The current research explains why agricultural programs advocate for farmers to have access to financial resources and to reasonably manage farming plots.

Involvement in farming activity and training was significant in Cluster 4, and income in all clusters, in general, was significant and increased the probability of adopting improved seeds in Cluster 3 and Cluster 4 and fertilizer in Cluster 5, respectively. Most farmers (95%) reported that farming was their main livelihood activity. This illustrates how farmers in African countries who are deemed experienced in agriculture know the importance of fertilizer and are more likely to adopt fertilizer technology (Nwakor, 2011; Victor Uzochukwu *et al.*, 2021b). Additionally, this awareness could determine farming operations on the ground, as well as their commitment and investments in agriculture (Asfaw and Admassie, 2004; Kondo *et al.*, 2020). Furthermore, most of the land is suitable for cassava farming. This finding elucidates how much cassava is appreciated by farmers and plays a significant role in food supply schemes. Cassava leaves and roots are very globally important in Africa and DRC since they are consumed annually and regularly. They constitute a major component of the local diet and serve as a crucial source of income for the population (Munyahali *et al.*, 2017). This crop also offers opportunities for employment and wealth creation for Congolese people throughout different segments of its value chain, from production and food processing to final consumption (Abdoulaye *et al.*, 2014; Alliance for a Green Revolution in Africa (AGRA), 2015; IITA, 2017).

Moreover, the land area was significant and increased the probability of adopting improved seeds in clusters 1, 2, and 3. Access to land is cited as an important factor in encouraging the adoption of agricultural practices by providing farmers with room for diversifying their operations (Lambrecht *et al.*, 2016; Mobio *et al.*, 2021). However, in the Eastern Democratic Republic of the Congo, arable land is becoming rare (Pypers *et al.*, 2011; Munyahali *et al.*, 2017). In the context of this study, the mean total land size assessed for farming was 0.41 hectares on average. This is because, in the Eastern DRC in general, people are concentrated in protected areas without violence or war where land is productive and accessible to infrastructure facilities (Simbeko *et al.*, 2023). Hence, 72% of the households surveyed owned a portion of land to be capitalized, as many lands were acquired by inheritance (65%), which is essential for allowing farmers to try different technologies with fewer restrictions. The latter agrees with the findings of Donkor *et al.* (2014) in Ghana, (Mubalama *et al.*, 2019) in South Kivu, and Kolapo and Kolapo, (2021) in Nigeria. Goswami *et al.* (2014) also found this in India; their study illustrated that smaller farms are inclined toward nonfarm income more than medium- and large farms are. In contrast, mid-sized and large farms have increasingly branched out, moving from a cereal-based system to a vegetable-based system. This requires holistic farm planning and extension intervention rather than confining efforts to technology transfer alone.

Nevertheless, geographic location had less impact on agriculture technologies adoption. This suggests that there is still a relative disparity and gap in the valorization of improved cassava varieties and cassava production practices level in different areas in the Eastern DRC region, according to Ouma *et al.* (2011). According to Priegnitz *et al.* (2019), some agricultural practices, such as technology and methods, require more labor than others because of diverse operations on the ground. Therefore, households with

Table 8. VIF tests summary – Tables 5–7.

Table and cluster	VIF range	Constant VIF	Signification
Table 5 – Cluster 1	1.08 to 1.27	54.56	No significant multicollinearity.
Table 5 – Cluster 2	1.10 to 1.27	78.79	No significant multicollinearity
Table 5 – Cluster 3	1.10 to 1.44	48.69	No significant multicollinearity
Table 5 – Cluster 4	1.05 to 1.29	63.57	No significant multicollinearity
Table 5 – Cluster 5	1.10 to 1.29	46.96	No significant multicollinearity
Table 6 – Cluster 1	1.07 to 1.32	57.40	No significant multicollinearity
Table 6 – Cluster 2	1.07 to 1.29	64.48	No significant multicollinearity
Table 6 – Cluster 3	1.11 to 1.27	56.93	No significant multicollinearity
Table 6 – Cluster 4	1.08 to 1.40	46.11	No significant multicollinearity
Table 6 – Cluster 5	1.05 to 1.28	47.07	No significant multicollinearity
Table 7 – Cluster 1	1.09 to 1.34	58.66	No significant multicollinearity
Table 7 – Cluster 2	1.09 to 1.29	62.19	No significant multicollinearity
Table 7 – Cluster 3	1.04 to 1.30	53.69	No significant multicollinearity
Table 7 – Cluster 4	1.08 to 1.25	79.10	No significant multicollinearity
Table 7 – Cluster 5	1.05 to 1.20	46.94	No significant multicollinearity

access to more labor are more likely to realize better achievements from farming than their counterpart, *ceteris paribus* (Makate and Mango, 2017). The size of a farming household is an important measure of labor in traditional agriculture. This has an impact on the adoption of fertilizer in South Kivu in this study in clusters 1 and 5. In the present study, improved seed selection criteria for household livelihoods were strongly dependent on high root yield, seed disease resistance (77%), and high leaf yield (47%). The latter was corroborated by other findings in South Africa (Makate and Mango, 2017) and South Kivu (Munyahali *et al.*, 2017; Yannick *et al.*, 2019). In addition, it appeared that farmers do not use tractors most of the time in land preparation. Most of them were small-scale farmers who frequently carried out land preparation, sowing, harvest, and weeding using manual materials. The results follow findings found from twenty countries in Africa conducted by Manyong *et al.* (2000). The latter demonstrated that cassava production is dominated by the small-scale farming system in Eastern Africa, covering approximately 1 to 2 acres. Because of the lower small field size, adopting such mechanized solutions becomes ridiculous even in locations where they are available. Additionally, most cassava fields in the Eastern DRC are situated in difficult terrain, which helps to explain why tractor use eventually became insufficient there.

The study also showed that field cleaning and disease control are inadequate for cassava plants. As shown in other studies (Ajeh and Uzokwe, 2008; Alonso Chavez *et al.*, 2021), most cassava producers obtain planting material from nearby farms and their own fields. In this way, cuttings are generated without correctly checking the foliage for disease symptoms, which perpetually activates viral infections. Farmers can avoid planting diseased material if they can correctly identify leaf or stem symptoms on the plants before the planting season (Chipeta *et al.*, 2016). A study on the adoption of improved cassava varieties that classified the traits into three different groups in Ghana found that farmers' preferred traits of cassava, such as longevity of root storage in the soil and disease resistance, significantly influenced their decision to adopt these varieties. This indicates that local knowledge and cultural beliefs can play a crucial role in the adoption of new agricultural technologies (Acheampong *et al.*, 2018). In summary, the VIF analysis for both South Kivu and Tanganyika confirms that the models are not concerned with multicollinearity issues.

METHODOLOGICAL AND EMPIRICAL APPROACH CONTRIBUTIONS AND IMPLICATIONS FOR THEORY

The present study revealed that the multivariate statistical techniques PCA and CA are suitable tools for identifying important socioeconomic characteristics of typical farm households that underlie the adoption of new technology, as attested by other findings around the world (Bidogeza *et al.*, 2007a; Alvarez *et al.*, 2014a; Makate and Mango, 2017; Mugumaarhahama *et al.*, 2021). Thus, the choice of multivariate analysis, specifically principal component analysis (PCA) and cluster analysis (CA), was justified in this study due to the complexity and multidimensional nature of factors influencing the adoption of cassava production technologies. The multivariate analysis allowed for the simultaneous examination of numerous variables to capture the inherent diversity among farmers, reducing data dimensionality while retaining critical variance. This approach enabled the classification of farmers into distinct clusters based on cassava practices and socioeconomic characteristics, providing a comprehensive understanding of adoption patterns. Compared to simpler methods, multivariate analysis ensures a more robust and nuanced analysis, accommodating interactions between variables. The differentiation of typical farms should help construct models based on typical farm households. With that, farmers can objectively be classified into different technology adopters. This study breaks away from traditional approaches used to characterize dominant farming systems economically. These conventional methods often rely on landholding or discussions with stakeholders. In contrast, this study first utilized multivariate statistics to identify different farm types. Second, a comprehensive set of agronomic, economic, and noneconomic variables is considered for classification and analysis. Furthermore, Hill and Smith's analysis was used for mixed quantitative and qualitative variables. This approach was innovative compared to that of other studies because it has the advantage of capturing the complexity of farming systems by considering several farm dimensions simultaneously and then highlighting a few dimensions that are more explanatory of farm diversity (Alvarez *et al.*, 2014a). This study further investigated the determinants of two technologies within each identified cluster: improved cassava seed and fertilizer usage, while the logit regression analyses were not compromised by multicollinearity, and the results derived from them can be

interpreted with confidence regarding predictor independence. This method accounted for the potential correlations between socioeconomic variables, like gender, age, farming experience, and land ownership, which significantly influence technology adoption patterns in different clusters. The results of this study are in line with those of SDG 1 and SDG 2, African Union's Agenda 2063 (African Union, 2006; UN, 2015), and other scholars (Manyong *et al.*, 2000; Tahirou *et al.*, 2015; Munyahali *et al.*, 2017; Makate *et al.*, 2018; Mubalama *et al.*, 2019; Casinga *et al.*, 2021). In particular, the objectives of increasing agricultural production and productivity, fighting poverty and hunger, and preserving and sustainably using biodiversity are needed to address food security issues. This study highlights the diversity among farm households in terms of how cassava improved the adoption of fertilizer technologies. Hence, this study builds upon existing findings on farmer typology and adoption of agricultural technology (Bidogeza *et al.*, 2007b; Alvarez *et al.*, 2014a; Makate *et al.*, 2018) through a comprehensive classification process. This study identified five distinct farm types that can be targeted for scaling up and readiness for agricultural technology. This methodology can be adapted and modified to suit different situations and objectives of farm typology studies.

STUDY LIMITATIONS

The variables employed in the principal component analysis (PCA) and cluster analysis (CA) in this study may differ based on the specific agroecosystem, agricultural practices, and the intended focus of farm characterization. In this research, the typology of farmers was initially established according to their agricultural practices. However, a key empirical weakness is the potential loss of information through dimensional reduction, as PCA may obscure subtle but relevant variations among variables. Additionally, clustering techniques depend on the initial data structure, which could result in subjective decisions about the number of clusters. These limitations indicate that findings should be interpreted with caution and supplemented with qualitative insights or additional statistical validation to minimize oversimplification and improve the representativeness of the identified farmer typologies. Other studies of other scopes could formulate farmer typologies based on both agricultural practices and socioeconomic factors. Furthermore, the development of data collection instruments should also consider these variations to ensure accurate and relevant results. The process of variable selection can actively involve stakeholders, thereby fostering widespread participation in the study. The multivariate approach utilized for farm-type delineation can be repurposed for the creation of a software and package support system. This system could feature distinct modules, each equipped with a versatile set of indicators. Following extensive multiplication field-testing, this tool could serve as a valuable resource for research and extension agencies, marking the next phase of ongoing research. Using logit regression in this study to analyze the causal effects of adopting improved cassava planting materials and fertilizers may present an empirical limit in the inherent assumption that each adoption decision is independent, potentially overlooking interaction effects between variables and across clusters. Additionally, while separate equations provide clarity in understanding specific drivers, they may not fully capture the interconnectedness of adoption behaviors, suggesting a limitation in explaining overlapping influences comprehensively. This highlights the need for considering additional models that might better capture complex interdependencies.

A potential limitation of this study regarding the adoption of improved cassava varieties and fertilizer technologies in the Democratic Republic of the Congo (DRC) is its inability to fully capture the complex socioeconomic and cultural factors that influence farmers' decisions. Although the typology offers a valuable framework for categorizing farmers based on their resources and farming practices, it may not sufficiently consider important aspects such as local knowledge, cultural beliefs, market access, and the influence of social networks. These factors

can significantly affect the use of agricultural technologies, and their omission could lead to an oversimplification of the realities on the ground. Therefore, while farmer's typology is a valuable tool, its application should be complemented with a nuanced understanding of the local context.

CONCLUSION AND POLICY IMPLICATIONS

This study revealed that, in the context of the Eastern region of the DRC, variation in the adoption of agricultural technologies for cassava production is associated with differences in the socioeconomic attributes of farmer diversity. The study came up with five distinct clusters of cassava farmers in the Eastern DRC, each exhibiting unique characteristics influencing adoption of technology. Cluster 1 comprises younger, less experienced farmers accounting for low adoption rates regarding improved cassava varieties and limited agricultural training. They select land with average fertility and give little preference to specific cassava traits. Targeted interventions for this group should focus on engaging the youths, providing comprehensive agricultural education, and offering incentives to encourage adoption of technology. Cluster 2 includes older, highly educated farmers who are selective about cassava variety traits, prioritizing high root yield and disease resistance. If endowed with substantial land in terms of ownership, this group would benefit from advanced agricultural practices and tailored advisory services.

Cluster 3 consists of less experienced but somewhat demanding farmers with moderate education. This category of farmers would gain from practical extension services emphasizing training and the economic benefits of high-yield cassava cultivars. Cluster 4 features older, experienced male farmers adhering to traditional practices (such as fallowing), and showing resistance to fertilizer use. This points to the need for appropriate interventions to promote sustainable soil fertility management and assert/showcase the benefits of using fertilizers. Cluster 5, the largest group, includes experienced female farmers who use many improved seeds but do not consistently adopt technology. Empowering women in this cluster through training, while also granting them access to resources and cooperative models could therefore boost productivity and use of technology.

This study highlights the need to strengthen and empower organizations/bodies involved in agricultural extension and is one of the few studies that laid emphasis on the influencing role of farmers' heterogeneity in the adoption of agricultural technologies regarding cassava in eastern DRC and Africa-wide. This aspect has long been overlooked in agricultural economic studies in the region, despite passing off as one of the main reasons behind the rejection of agricultural innovations. Hence, five major types of farms were identified, based on best agricultural practices among farmers. This study sought to assess at which rates the various kinds of farmer households in Eastern DRC adopted new technology for cassava production. Given that certain farm types exhibit greater propensity for technology adoption, it would be wise to tailor extension related messages and policies in a manner to cater for specific groups' needs, including the five farm types identified in this study. This targeted approach can enhance the effectiveness of these initiatives. Data from 1,317 agricultural households were analyzed, and 65 distinct criteria were considered. The results showed that the adoption of improved cassava seeds and few factors influenced fertilizer use among these five farmer groups. These factors included years of farming experience and trainings, marital status, income, engagement in agricultural activities, land area, gender, age of farmers, education level, and the land on which cassava is grown.

As specified in the study, stakeholder initiatives aimed at advancing agricultural technologies had to be customized to suit respective cohorts of farmers and the socioeconomic factors revealed by the research. Additionally, study (1) offered insightful information for developing policies and plans for disseminating agricultural

innovations throughout the DRC. (2) The authors stressed the worthiness of establishing efficient institutional frameworks for extension services to accelerate the adoption of technologies for cassava production growth. Additionally, number of aspects were suggested, with the purposes of improving the use of fertilizers and planting materials for cassava, (3) laying emphasis on elements such as land area, land ownership, agricultural experience, marital status, and gender-sensitive decision-making. To sum it all up, not only does this study methodically contribute to understanding farm typologies and socioeconomic determinants of technology adoption, but it also (4) provides for guidance for future research on various agricultural practices and technology adoption, way beyond the scope of cassava seed and fertilizer technologies. (5) The need for policies that underpin the sustainable enhancement of cassava productivity should be emphasized, as should the role of the government and NGOs in promoting factors conducive for technology adoption and sustainable agriculture in the DRC. On their side, DRC's policymakers should set priority on establishing effective institutional structures with potential to promote the adoption of availed cassava farming technologies.

ABBREVIATIONS

AGRA	Green Revolution in Africa
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
CA	Cluster analysis
CAD	Cassava Anthracnose Disease
CBBB	Cassava Bacterial Blight Disease
CBSD	Cassava Brown Streak Disease
CIAT	International Center for Tropical Agriculture
CICR	International Committee of the Red Cross
CMD	Cassava Mosaic Disease
DRC	Democratic Republic of the Congo
FAO	Food and Agriculture Organization of the United Nations
GAPs	Good agricultural practices
IITA	International Institute of Tropical Agriculture
INERA	National Institute for Agronomic Study and Research
IRB	Internal Review Board
ITAV	Agricultural and Veterinary Technical Institute
KMO	Kaiser-Meyer-Olkin
ODK	Open Data Collection Kit
PC	Principal Components
PCA	Principal component analysis
PICAGL	The Regional Integrated Agricultural Development Project Great Lakes
MAP	Months after planting
SD	Standard deviation
SIA	Services d'inspection agricole
USD	United States dollar
VIF	Variance Inflation Factor

CONFLICTS OF INTEREST

The authors declare no competing interests.

ETHICS STATEMENT

The authors confirm that the research meets any required ethical guidelines, including adherence to the legal requirements of the study country.

ACKNOWLEDGMENTS

We would like to thank the IITA socioeconomic team for providing material for data analysis and curation, providing permission for figures illustrating activities on ground and the PICAGL team for providing all the administration support, which contributed to this work.

AUTHOR CONTRIBUTIONS

Conceptualization, N.L.N., S.A.; and G.S.; methodology, G.S. and S.A.; software, G.S.; validation, N.L.N., G.S., S.A., and J.C.M.; formal analysis, G.S.; investigation, G.M.M.; C.K. and F.B.B.; resources, B.V. and J.M.; data curation, G.S., P.M.M.; writing—original draft preparation, G.S., J.C.M., and S.A.; writing—review and editing, G.S., P.U.; P.D.N., F.B.B., and K.K.; visualization, G.S.; supervision, N.L.N.; project administration, J.M.; funding acquisition, B.V. All authors have read and agreed to the published version of the manuscript.

FUNDING STATEMENT

Financial support was from the Integrated Project for Agriculture Growth in the Great Lakes Region (PICAGL, Project ID: P143307) funded by the World Bank Group via the Government of the Democratic Republic of the Congo and implemented by the International Institute of Tropical Agriculture (IITA) in South Kivu and Tanganyika provinces.

DATA AVAILABILITY

The dataset supporting the conclusions of this article is included within the article and its additional files.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

References

- Abdoulaye, T., Abass, A., Maziya-Dixon, B., Tarawali, G., Okechukwu, R. *et al.* (2014) Awareness and adoption of improved cassava varieties and processing technologies in Nigeria. *Journal of Development and Agricultural Economics* 6, 67–75. DOI: 10.5897/jdae2013.006.
- Acheampong, P.P., Owusu, V. and Nurah, G. (2018) How does farmer preference matter in crop variety adoption? The case of improved cassava varieties' adoption in Ghana. *Open Agriculture* 3, 466–477. DOI: 10.1515/opag-2018-0052.
- African Union (2006) African Union Youth Charter.
- Ajeh, P. and Uzokwe, U. (2008) Adoption of cassava production technologies among women farmers in aniocha south local government area (Lga), Delta State, Nigeria. *Global Approaches to Extension Practice: A Journal of Agricultural Extension* 3, 7–12. DOI: 10.4314/gaep.v3i2.34908.
- Alliance for a Green Revolution in Africa (AGRA) (2015) Africa Agriculture Status Report-2015 [WWW Document]. Available at: <https://agra.org/wp-content/uploads/2021/03/africa-agriculture-status-report-2015.pdf> (accessed 15 September 2020).
- Alonso Chavez, V., Milne, A.E., van den Bosch, F., Pita, J. and McQuaid, C.F. (2021) Modelling cassava production and pest management under biotic and abiotic constraints. *Plant Molecular Biology* 109, 325–349. DOI: 10.1007/s11103-021-01170-8.
- Alvarez, S., Paas, W., Descheemaeker, K., Tittonell, P. and Groot, J. (2014a) Constructing typologies, a way to deal with farm diversity: general guidelines for the Humidtropics. In: *Report for the CGIAR Research Program on Integrated Systems for the Humid Tropics*. Plant Sciences Group Report, pp. 1–37.

- Alvarez, S., Paas, W., Descheemaeker, K., Tittonell, P. and Groot, C.J. (2014b) Constructing typologies, a way to deal with farm diversity: general guidelines for the Humidtropics. In: *Report for the CGIAR Research Program on Integrated Systems for the Humid Tropics*. Plant Sciences Group, Wageningen University, the Netherlands, pp. 1–37.
- Alvarez, S., Timler, C.J., Michalscheck, M., Paas, W., Descheemaeker, K. et al. (2018) Capturing farm diversity with hypothesis-based typologies: An innovative methodological framework for farming system typology development. *PLoS ONE* 13, 1–24. DOI: 10.1371/journal.pone.0194757.
- Asfaw, A. and Admassie, A. (2004) The role of education on the adoption of chemical fertiliser under different socioeconomic environments in Ethiopia. *Agricultural Economics* 30, 215–228. DOI: 10.1111/j.1574-0862.2004.tb00190.x.
- Ayoola, O.T. and Makinde, E.A. (2007) Complementary organic and inorganic fertilizer application: Influence on growth and yield of cassava/maize/melon intercrop with a relayed cowpea. *Australian Journal of Basic and Applied Sciences* 1, 187–192.
- Bidogeza, J.C., Berentsen, P.B.M., Graaff, J. and Oude Lansink, A.G.J.M. (2007a) *Multivariate Typology of Farm Households Based on Socio-Economic Characteristics Explaining Adoption of New Technology in Rwanda*. AAAE Ghana Conference, pp. 275–281.
- Bidogeza, J.C., Berentsen, P.B.M., Graaff, J. and Oude Lansink, A.G.J.M. (2007b) *Multivariate Typology of Farm Households Based on Socio-Economic Characteristics Explaining Adoption of New Technology in Rwanda*. AAAE Ghana Conference, pp. 275–281.
- Casinga, C.M., Shirima, R.R., Mahungu, N.M., Tata-Hangy, W., Bashizi, K.B. et al. (2021) *Expansion of the Cassava Brown Streak Disease Epidemic in Eastern Democratic Republic of Congo*. American Phytopathological Society (APS), St. Paul, MN. DOI: 10.1094/PDIS-05-20-1135-RE 105.
- Chipeta, M.M., Shanahan, P., Melis, R., Sibiya, J. and Benesi, I.R.M. (2016) Farmers' knowledge of cassava brown streak disease and its management in Malawi. *International Journal of Pest Management* 62, 175–184. DOI: 10.1080/09670874.2016.1167268.
- Donkor, E., Owusu, V. and Owusu-Sekyere, E. (2014) Assessing the determinants of adoption of improved cassava varieties among farmers in the ashanti region of Ghana. *Africa Development and Resources Research Institute Journal* 5, 92–104.
- Dontsop Nguetzet, P.M., Ainembabazi, J.H., Alene, A., Abdulaye, T., Feleke, S. et al. (2020) Are farmers using cropping system intensification technologies experiencing poverty reduction in the Great Lakes Region of Africa? *Food and Energy Security* 9, 1–19. DOI: 10.1002/fes3.205.
- Ezui, K.S., Franke, A.C., Ahiabor, B.D.K., Tetteh, F.M., Sogbedji, J. et al. (2017) Understanding cassava yield response to soil and fertilizer nutrient supply in West Africa. *Plant and Soil* 420, 331–347. DOI: 10.1007/s11104-017-3387-6.
- FAO (2022) *Championing the Cause of Cassava* [WWW Document]. Available at: <https://www.fao.org/NEWS/2000/000405-e.htm> (accessed 3 November 2022).
- Fermont, A.M., Tittonell, P.A., Baguma, Y., Ntawuruhunga, P. and Giller, K.E. (2010) Towards understanding factors that govern fertilizer response in cassava: Lessons from East Africa. *Nutrient Cycling in Agroecosystems* 86, 133–151. DOI: 10.1007/s10705-009-9278-3.
- Gebrekidan, B.H., Heckeleti, T. and Rasch, S. (2020) Characterizing farmers and farming system in Kilombero Valley Floodplain, Tanzania. *Sustainability (Switzerland)* 12, 2–6. DOI: 10.3390/su12177114.
- Goswami, R., Chatterjee, S. and Prasad, B. (2014) Farm types and their economic characterization in complex agro-ecosystems for informed extension intervention: study from coastal West Bengal, India. *Agricultural and Food Economics* 2, 11–22. DOI: 10.1186/s40100-014-0005-2.
- Hair, J. (2009) *Multivariate Data Analysis* 7th Edition 2009 1.
- Harry, A.T. and Otto, C.B. (2019) *Community Adoption on Cassava Technology Packages in Elele Alimini Enuoha Local Government Area of Rivers State*. Researchgate.Net, Nigeria. DOI: 10.9790/487X-2102036875.
- Hertel, G., Konradt, U. and Voss, K. (2006) Competencies for virtual teamwork: Development and validation of a web-based selection tool for members of distributed teams. *European Journal of Work and Organizational Psychology* 15, 477–504. DOI: 10.1080/13594320600908187.
- Humpal, D., Musangu, B. and Tunieka, M. (2012) *Cassava Value Chain Assessment: Bas-Congo, Kinshasa, and Bandundu Provinces*.
- IITA (2017) *2017 Annual Report: Serving the African Farmers and Communities* 124.
- Joshua Udoh, E. and Titus Omonona, B. (2008) Improved rice variety adoption and its welfare impact on rural farming households in akwa ibom state of Nigeria. *Journal of New Seeds* 9, 156–173. DOI: 10.1080/15228860802087305.
- Kaluba, P., Mwamba, S., Moualeu-Ngangue, D.P., Chiona, M., Munyinda, K. et al. (2021) Cropping practices and effects on soil nutrient adequacy levels and cassava yield of smallholder farmers in Northern Zambia. *International Journal of Agronomy* 2021, 15–17. DOI: 10.1155/2021/1325964.
- Khandoker, S., Singh, A. and Srivastava, S.K. (2022) Leveraging farm production diversity for dietary diversity: evidence from national level panel data. *Agricultural and Food Economics* 10, 23–32. DOI: 10.1186/s40100-022-00221-y.
- Kilwinger, F., Mugambi, S., Manners, R., Schut, M., Tumwegamire, S., Nduwumuremyi, A. and Bambara, S. (2021) Characterizing cassava farmer typologies and their seed sourcing practices to explore opportunities for economically sustainable seed business models in Rwanda. *SAGE Open* 50, 441–454. DOI: 10.1177/00307270211045408.
- Kintché, K., Hauser, S., Mahungu, N.M., Ndonda, A., Lukombo, S. et al. (2017) Cassava yield loss in farmer fields was mainly caused by low soil fertility and suboptimal management practices in two provinces of the Democratic Republic of Congo. *European Journal of Agronomy* 89, 107–123. DOI: 10.1016/j.eja.2017.06.011.
- Kolapo, A. and Kolapo, A.J. (2021) Welfare and productivity impact of adoption of biofortified cassava by smallholder farmers in Nigeria. *Cogent Food and Agriculture* 7, 3–8. DOI: 10.1080/23311932.2021.1886662.
- Kondo, K., Cacho, O., Fleming, E., Villano, R.A. and Asante, B.O. (2020) Dissemination strategies and the adoption of improved agricultural technologies: The case of improved cassava varieties in Ghana. *Technology in Society* 63, 101408. DOI: 10.1016/j.techsoc.2020.101408.
- Kreye, C., Hauser, S., Pypers, P. and Vanlauwe, B. (2020) Intensification options of small holders' cassava production in South-west Nigeria. *Agronomy Journal* 112, 5312–5324. DOI: 10.1002/agj2.20419.
- Lambrecht, I., Vanlauwe, B. and Maertens, M. (2016) Integrated soil fertility management: from concept to practice in Eastern DR Congo. *International Journal of Agricultural Sustainability* 14, 100–118. DOI: 10.1080/14735903.2015.1026047.
- Mabe, F.N., Donkoh, S.A. and Al-Hassan, S. (2019) Technology adoption typology and rice yield differentials in Ghana: Principal component analysis approach. *African Journal of Science, Technology, Innovation and Development* 11, 555–567. DOI: 10.1080/20421338.2018.1551849.
- Makate, C. and Mango, N. (2017) Diversity amongst farm households and achievements from multi-stakeholder innovation platform approach: Lessons from Balaka Malawi. *Agriculture and Food Security* 6, 1–15. DOI: 10.1186/s40066-017-0115-7.
- Makate, C., Makate, M. and Mango, N. (2018) Farm types and adoption of proven innovative practices in smallholder bean farming in Angonia district of Mozambique. *International Journal of Social Economics* 45, 140–157. DOI: 10.1108/IJSE-11-2016-0318.
- Manyong, V.M., Makinde, K.O., Bokanga, M. and Whyte, J. (2000) *The Contribution of IITA-Improved Cassava to Food Security in Sub-Saharan Africa: An Impact Study*. International Institute of Tropical Agriculture, Ibadan, Nigeria.
- Martey, E., Wiredu, A.N., Etwire, P.M., Fosu, M., Buah, S.S.J. et al. (2013) Fertilizer adoption and use intensity among smallholder farmers in Northern Ghana: A case study of the AGRA soil health project. *Sustainable Agriculture Research* 3, 24. DOI: 10.5539/sar.v3n1p24.
- Mekonnen, D.A., Adeyemi, O., Gilbert, R., Akerele, D., Achterbosch, T. and Herforth, A. (2023) Affordability of healthy diets is associated with increased food systems performance in Nigeria: State-level analysis. *Agricultural and Food Economics* 11, 5–12. DOI: 10.1186/s40100-023-00263-w.
- Mobio, A.J., Fokou, G., Aka, S., Kouassi, K.B., Kreppel, K.S. et al. (2021) Exploring beyond the conjunctural rhetoric: sociocultural drivers for the “cassava crisis” in Côte d'Ivoire. *Agricultural and Food Economics* 9. DOI: 10.1186/s40100-020-00174-0.

- Mubalama, J.M., Ayagirwe, R.B.B., Martin, P., Nguetzet, D., Mondo, J.M. et al. (2019) Determinants of adoption and farmers' preferences for cassava varieties in kabare territory, eastern democratic Republic of Congo. *American Journal of Rural Development* 7, 44–52. DOI: 10.12691/ajrd-7-2-1.
- Muengula-Manyi, M., Nkongolo, K.K., Bragard, C., Tshilenge-Djim, P., Winter, S. and Kalonji-Mbuyi, A. (2012) Incidence, severity and gravity of cassava mosaic disease in savannah agro-ecological region of DR-Congo: Analysis of agro-environmental factors. *American Journal of Plant Sciences* 03, 512–519. DOI: 10.4236/ajps.2012.34061.
- Mugumaarhahama, Y., Mondo, J.M., Cokola, M.C., Ndjadi, S.S., Mutwedu, V.B. et al. (2021) Socio-economic drivers of improved sweet potato varieties adoption among smallholder farmers in South-Kivu Province, DR Congo. *Scientific African* 12, e00818. DOI: 10.1016/j.sciaf.2021.e00818.
- Munyahali, W., Pypers, P., Swennen, R., Walangululu, J., Vanlauwe, B. and Merckx, R. (2017) Responses of cassava growth and yield to leaf harvesting frequency and NPK fertilizer in South Kivu, Democratic Republic of Congo. *Field Crops Research* 214, 194–201. DOI: 10.1016/j.fcr.2017.09.018.
- Musafiri, C.M., Macharia, J.M., Ng'etich, O.K., Kiboi, M.N., Okeyo, J. et al. (2020) Farming systems' typologies analysis to inform agricultural greenhouse gas emissions potential from smallholder rain-fed farms in Kenya. *Scientific African* 8, 19–22. DOI: 10.1016/j.sciaf.2020.e00458.
- Nguetzet, P.M.D., Diagne, A., Okoruwa, V.O. and Ojehomon, V. (2011) Impact of improved rice technology (NERICA varieties) on income and poverty among rice farming households in Nigeria: A local average treatment effect (LATE) approach. *Quarterly Journal of International Agriculture* 50, 267–291. DOI: 10.22004/ag.econ.155535.
- Nwakor, F.N. (2011) Socio-economic factors affecting adoption of improved cassava varieties among farmers in abia state. *African Journal of Agricultural Research* 45, 1–7.
- Nwaobiala, C. (2017) Farmers' adoption of cassava agronomic practices and intercrop technologies in Abia and Imo States, Nigeria. *Journal of Agriculture Extension* 22(2), 82–96.
- Nweke, F.I., Lutete, D., Dixon, A.G.O., Ugwu, B.O., Ajobo, O., Kalombo, N. and Bukaka, B. (2000) *Cassava Production and Processing in the Democratic Republic of Congo*. IITA COSCA.
- Oloruntola, O.D. (2020) Effect of dietary cassava peel meal supplemented with methionine and multienzyme on hemo-biochemical indices, digestibility, and antioxidants in rabbits. *The Journal of Basic and Applied Zoology* 81, 26–28. DOI: 10.1186/s41936-020-00170-2.
- Onasanya, O.O., Hauser, S., Necpalova, M., Salako, F.K., Kreye, C. et al. (2021) On-farm assessment of cassava root yield response to tillage, plant density, weed control and fertilizer application in southwestern Nigeria. *Field Crops Research* 262, 108038. DOI: 10.1016/j.fcr.2020.108038.
- Onyemima, J.O., Tokula, M., Tertsea, K.M. and Chimela, N.S. (2019) Impact of improved cassava technology adoption on farmers output in Benue state, Nigeria. *Journal of Agricultural and Life Sciences (JALSI)* 21, 1–10. DOI: 10.9734/JALSI/2019/v21i430112.
- Ouma, E., Birachi, E., Pypers, P., Vanlauwe, B., Ekesa, B. et al. (2011) *CIALCA Technical Report 17 CIALCA Baseline Survey*. Cialca.Org.
- Priegnitz, U., Lommen, W.J.M., Onakuse, S. and Struik, P.C. (2019) A farm typology for adoption of innovations in potato production in Southwestern Uganda. *Frontiers in Sustainable Food Systems* 3, 1–15. DOI: 10.3389/fsufs.2019.00068.
- Pypers, P., Sanginga, J., Kasereka, B., Walangululu, M. and Vanlauwe, B. (2011) Field crops research increased productivity through integrated soil fertility management in cassava – Legume intercropping systems in the highlands of Sud-Kivu, DR Congo. *Field Crops Research* 120, 76–85. DOI: 10.1016/j.fcr.2010.09.004.
- Revelle, W. (2017) How to use the psych package for mediation/moderation/regression analysis. *Organization Studies* 27, 1485–1511.
- Sarker, M.R., Galdos, M.V., Challinor, A.J. and Hossain, A. (2021a) A farming system typology for the adoption of new technology in Bangladesh. *Food and Energy Security* 10, 1–18. DOI: 10.1002/fes3.287.
- Sarker, M.R., Galdos, M.V., Challinor, A.J. and Hossain, A. (2021b) A farming system typology for the adoption of new technology in Bangladesh. *Food and Energy Security* 10, 1–18. DOI: 10.1002/fes3.287.
- Shrestha, N. (2021) Factor analysis as a tool for survey analysis. *American Journal of Applied Mathematics and Statistics* 9, 4–11. DOI: 10.12691/ajams-9-1-2.
- Simbeko, G., Nguetzet, P.M.D., Sekabira, H., Yami, M., Masirika, S.A. et al. (2023) Entrepreneurial Potential and Agribusiness Desirability among Youths in South Kivu, Democratic Republic of the Congo. *Sustainability (Switzerland)* 15, 13–20. DOI: 10.3390/su15010873.
- Tahirou, A., Bamire, A.S., Oparinde, A. and Akinola, A.A. (2015) Determinants of adoption of improved cassava varieties among farming households in Oyo, Benue, and Akwa Ibom States of Nigeria. *HarvestPlus Working Paper* 22, 21.
- Tittonell, P., Bruzzone, O., Solano-Hernández, A., López-Ridaura, S. and Easdale, M.H. (2020) Functional farm household typologies through archetypal responses to disturbances. *Agricultural Systems* 178. DOI: 10.1016/j.agry.2019.102714.
- UN (2015) The 2030 Agenda for Sustainable Development's 17 Sustainable Development Goals (SDGs).
- Victor Uzochukwu, U., Godwin Mgbedike, N. and Aloysius Chukwujekwu, O. (2021a) Adoption of improved cassava production technologies among small-scale farmers in Anambra State, Nigeria. *Journal of Plant Sciences* 9, 119. DOI: 10.11648/j.jps.20210904.11.
- Victor Uzochukwu, U., Godwin Mgbedike, N. and Aloysius Chukwujekwu, O. (2021b) Adoption of improved cassava production technologies among small-scale farmers in Anambra State, Nigeria. *Journal of Plant Sciences* 9, 119. DOI: 10.11648/j.jps.20210904.11.
- Vurro, M., Bonciani, B. and Vannacci, G. (2010) Emerging infectious diseases of crop plants in developing countries: Impact on agriculture and socio-economic consequences. *Food Security* 2, 113–132. DOI: 10.1007/s12571-010-0062-7.
- Wooldridge, J.M. (2002) *Econometric Analysis of Cross Section and Panel Data*.
- Yannick, M.L., Victor, M.M., Roger, N.M. and Meso, M.N. (2019) Dynamique Socio-Économique de l'adoption des Variétés Améliorées du Manioc en République Démocratique du Congo (RDC): Cas des Provinces de Kongo Central et la Tshopo. *European Scientific Journal ESJ* 15, 346–362. DOI: 10.19044/esj.2019.v15n15p346.