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Adoption and Impact of Superior Banana Varieties in Kagera, Tanzania:

A guide for future distribution of banana breakthrough products

Shiferaw Feleke, Happiness Zacharia, Mussa Nyaa,
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Acronyms and Abbreviations

ARDI	Agricultural Research and Development Institute
ATT	Average Treatment Effects on the Treated
BXW	Banana Xanthomonas Wilt
CAPI	Computer-Assisted Personal Interviewing
ENABEL	Belgian Agency for International Cooperation
EAHB	East African Highland Bananas
ESR	Endogenous Switching Regression
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus group discussions
FGT	Foster, Greer, and Thorbecke
FHIA	Fundación Hondureña de Investigación Agrícola
FIML	Full Information Maximum Likelihood
GPS	Global Positioning System
IITA	International Institute of Agriculture
KCDP	Kagera Community Development Programme
KIIs	Key informant interviews
MOA	Ministry of Agriculture
NARO	National Agricultural Research Organisation in Uganda
NBS	National Bureau of Statistics
PPP	Purchasing Power Parity
PPS	Probability proportional to size
QGIS	Quantum Geographic Information System
SBV	Superior Banana Variety
TARI	Tanzania Agricultural Research Institute
TLU	Tropical Livestock Unit
URT	United Republic of Tanzania

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Executive summary

Tanzania is the second-largest banana producer in Eastern Africa, after Uganda. Kagera is the top banana-producing region in Tanzania, accounting for more than half of the country's banana production, despite diseases and pests having long plagued banana production in that region. Smallholder farmers in the region have been highly vulnerable to food and income insecurity for decades, as all varieties are susceptible to major diseases and pests that cause significant yield losses. Banana farmers, as well as governmental and nongovernmental organizations, have made considerable efforts to address the disease and pest challenges for decades. Farmers have been introducing "exotic" varieties from neighboring regions and countries since the 1960s. The Government of Tanzania (via TARI-Maruku, formerly ARDI-Maruku) and Belgium (via the Belgian Agency for International Cooperation (ENABEL), formerly the Belgian Administration for Development and Cooperation) cofinanced two significant initiatives: the Kagera Community Development Programme (KCDP) for five years from 1997 to 2003 and the Sustainable Improvement of Banana Cropping System (2009–2013). KCDP facilitated the introduction, propagation, and dissemination of new varieties, known as "Superior Banana Varieties" (SBVs), as of 1997. The SBVs include FHIA hybrids, as well as other hybrids developed through collaborative efforts among IITA, NARO, and TARI. Additionally, they comprise exotic landraces introduced from Kagera's neighboring regions and Tanzania's neighboring countries. Despite the widespread dissemination of SBVs for nearly 25 years, both directly and indirectly (from farmer to farmer), there is a lack of adequate, systematically organized information on the contexts surrounding the uptake, adoption rates, determinants of adoption, and socioeconomic impacts. As a result, it is difficult to determine whether the banana improvement initiatives have achieved the intended socioeconomic impacts, such as productivity gains and improvements in household food security. Moreover, these past interventions can provide guidance to the banana breeding programs of the International Institute of Tropical Agriculture (IITA) and Tanzania Agricultural Research Institute (TARI) on how to accelerate the testing and distribution of breakthrough products from the banana breeding pipelines, which are now available.

We conducted an adoption and impact study in Kagera in two phases in late 2024. The first phase aimed to understand the technological, biophysical, and socioeconomic contexts of the adoption of SBVs using qualitative methods, which involved focus group discussions (FGDs) with smallholder farmers and key informant interviews (KIIs) with banana value chain actors (e.g., processors and traders), and stakeholders (e.g., extension workers, researchers, policymakers, and development practitioners). The second phase aimed to quantify the adoption rate of SBVs and their socioeconomic impacts using household survey data collected from a random sample of banana farmers.

This report presents the results of the adoption and impact study of SBVs in the Kagera region of Tanzania. Specifically, the report provides: (i) the context surrounding the adoption of SBVs and their associated impacts, focusing on the technological characteristics (e.g., farmers' needs, desirable traits such as disease resistance, culinary qualities, marketability, production priorities for own consumption and sales), farmers' biophysical and socioeconomic characteristics (awareness, access, availability, resources, markets) that influence adoption and its impact; (ii) adoption rates of SBVs, agronomic practices and determinants, (iii) the relationship between adoption and intermediate outcomes such as surplus production,

sales, and disease/pest mitigation (iv) productivity and household food security impact, (v) gender gaps in SBV adoption, banana productivity and household income, and (vi) the direct contribution of the SBVs to the Kagera's economy.

(i) **Context surrounding SBV adoption**

Variety types grown: Farmers cultivate endemic landraces, i.e., East African Highland Bananas (EAHBs) and SBVs, which comprise FHIA hybrids developed by the Fundación Hondureña de Investigación Agrícola and other hybrids developed by IITA in collaboration with the Uganda National Agricultural Research Organisation (NARO) and TARI. The farmers cultivated FHIA hybrids because they have higher productivity and better market demand and prices, while maintaining the EAHBs, which are intertwined with cultural heritage and traditional dishes.

Awareness and source of planting materials: Most farmers became aware of SBVs and acquired planting materials from demonstration fields, fellow farmers, friends, neighbors, and relatives, underscoring the need to strengthen the farmer-to-farmer dissemination approach to guide the distribution of the recently released banana hybrids and future improved banana varieties.

Preference traits and varieties: Farmers' preferred traits and adoption criteria include tolerance to diseases and pests, adaptability to poor soil conditions, minimal organic fertilizer requirements, high yields (big fingers and bunches), better quality for juice and brewing, multipurpose (as cooking, dessert, and roasting), and strong marketability. FHIA 17 and FHIA 23 are preferred for cooking and dessert, while FHIA 25 and Yangambi KM 5 are preferred for beverage making. Processors want to see additional traits integrated into some of the hybrids (e.g., increased sweetness or higher sugar content for FHIA 25 and a longer shelf life for Yangambi KM 5). Traders prioritize bunch size, finger size, sweet taste, and longer shelf life. These results guide the selection of traits to consider in the breeding program.

Production constraints: Banana farmers reported production constraints such as diseases, pests, and moisture stress (as reported by 84% of the respondents), a lack of knowledge about improved agronomic and crop protection practices (reported by 80% of respondents), a lack of access to inputs (such as improved banana varieties reported by 72% of respondents), low price incentives (reported by 70% of respondents), a lack of marketing information, and broker interference (reported by 60%).

(ii) **Adoption rates of SBVs, determinants, and agronomic practices**

SBV adoption rate: Farmers cultivate as many as seven SBVs. The adoption rate of SBVs in Kagera (measured by cultivating at least one variety in 2024) was 48%, with 38.3% having adopted one SBV, 6.3% having two SBVs, and 3.4% having a combination of three or more SBVs (FHIA 17, FHIA 23, FHIA 25, and Yangambi KM 5). The three most adopted SBVs are FHIA 17 at 25% of farmers, followed by FHIA 23 (6.6%), and FHIA 25 (3.5%). The determinants of SBV adoption include the age of the household head, sex of the banana plot manager, banana farm size, access to credit, elevation, and geographical location of residence.

*Agronomic practices***:** Only a few agronomic practices are widely used. The most common practices are desuckering, hand weeding, mulching, and propping. Improved practices, such as treating/disinfecting sucker corm, pesticides, postharvest management (to increase shelf life), chemical fertilizers, bunch thinning, and dehandling false hands, are notably absent. Deflowering and herbicides are emerging practices.

(iii) **Relationship between adoption and intermediate outcomes**

Adoption and farmers' vulnerability to diseases and pests: Banana diseases and pests remain a critical threat to banana cultivation, affecting more than half of the farmers in the region. Farmers experience three banana diseases (Fusarium wilt [Panama disease], black leaf streak [Sigatoka], Banana Xanthomonas Wilt [BXW]) and two pests (weevils and nematodes), with moderate to extreme severity. The adoption of SBVs exhibited a systematic association with the incidence of the three diseases. The odds of an adopter being vulnerable to the three diseases are at least half as high as those of a nonadopter. However, there were no statistically significant differences in the percentage of adopters and nonadopters experiencing pest incidence. Adopters and nonadopters are equally affected by pests.

Adoption, surplus production, and sales: The adoption of SBVs is also systematically associated with surplus production and market sales. Adopters are 1.6 times more likely to be surplus producers and 2.6 times more likely to sell bananas than nonadopters. Kagera's banana production enters larger markets in nearby regions (e.g., Shinyanga, Tabora, Geita, Singida, and Mwanza) and distant markets (e.g., Dodoma and Dar es Salaam) that offer better prices.

Gender and household decision-making in banana sales: Men are predominantly the decision-makers on the income from the sales of all types of bananas (cooking, roasting, beverage, and dessert). However, there is a systematic association between the adoption of SBVs and household decision-making in banana sales. Women in the adopter group are 1.3 times more likely to make sales decisions than those in the nonadopter group.

(iv) **Productivity and household food security impacts**

SBV adopters achieved a 15% gain in productivity (1.8 tons/ha), with yields rising from 12.2 tons/ha without adoption to 14.0 tons/ha with adoption ($p < 0.01$). The SBVs resulted in improved household food security, measured by the per capita calorie consumption (physical access). The average per capita caloric intake per day with adoption in 2024 was 3,165 kcal, compared to 2,491 kcal without adoption (representing a 27% increase), translating into a 10-percentage-point reduction in the incidence, a six-percentage-point decrease in the depth, and a four-percentage-point decrease in the severity of household food insecurity. An estimated 20,934 food-insecure adopting households (equivalent to 125,602 individuals) became food secure.

(v) **Gender gaps in SBV adoption, banana productivity, and household income**

Results revealed gender gaps in the probability of adopting SBVs. The probability of adopting SBVs is lower for households with female-managed plots compared to those with jointly managed plots. Further, there are gender gaps in banana productivity and household income among adopters. Adopters with women-managed plots are less productive and earn lower incomes than those with jointly managed plots. In contrast, adopters with men-managed plots are equally likely to be as productive and earn incomes equal to those with jointly managed plots. These results suggest that a more targeted approach to increase women's access to SBVs could lead to overall increased banana production, higher incomes, and improved household food security.

(vi) **Direct contribution of SBV adoption to Kagera's economy**

The 15% productivity gain due to SBV adoption resulted in 119,194 tons of bananas in Kagera by 2024, contributing nearly 7 million USD yearly to the region's economy. The added outputs account for 10.5% of Kagera's and 6.1% of mainland Tanzania's banana production.

Conclusion

The results present significant evidence supporting past interventions in the banana breeding program and the promotion of the SBVs, including the newly released matooke banana hybrids among nonadopters. It is thus essential to increase investments in banana research and scaling of the resulting innovations to address a broader range of production constraints and raise banana yields. The results on farmers' contexts (i.e., needs, priorities, constraints), adoption rates, barriers, productivity, and impacts suggest a strong demand from banana value chain actors (farmers, processors, traders), which is essential for the future distribution of banana breakthrough products.

Introduction

The African Great Lakes Region is home to a unique set of banana landraces, known as the East African Highland Bananas (EAHBs), which include both cooking and brewing types. Tanzania is the second-largest banana producer in Eastern Africa, after Uganda. Banana production is primarily concentrated in the Lake Zone (Kagera Region), followed by the Eastern Zone (Morogoro and Coast Regions), Northern Zone (Kilimanjaro, Arusha, and Moshi), and Southern Highland Zone (Mbeya) (Ndunguru, 2009). Kagera is the leading banana-producing region in Tanzania, accounting for over half of the country's banana production (NBS, 2024). It is endowed with diverse indigenous banana varieties, categorized into cooking, brewing, and roasting types. Cooking bananas, often referred to as Matooke, are the most dominant types, accounting for over half of the total banana stands in most home gardens. However, all cultivars are susceptible to diseases and pests, particularly Sigatoka, weevils, and nematodes (Viljoen et al., 2016; Nkuba et al., 2015; Shimwela et al., 2016). Fusarium wilt (Panama disease) can cause complete yield losses in susceptible cultivars, such as Gros Michel (Rizal et al., 2025), Kayinja, and Sukari Ndizi. Sigatoka causes yield losses, ranging from 30% to 50% (Viljoen et al. 2016). Weevils and nematodes can cause yield losses, ranging from 30% to 70% (Wairegi et al., 2010).

To mitigate the yield losses, banana farmers in the Kagera region introduced "exotic" varieties from neighboring regions (Eastern, Northern, and Southern Highlands) and neighboring countries (Burundi, Rwanda, and Uganda) in the 1960s and 1970s (Kikulwe et al., 2007). However, none of the introduced varieties were effective in tolerating diseases and pests. Hence, the Government of Tanzania (via TARI-Maruku, formerly ARDI-Maruku) and Belgium (via the Belgian Agency for International Cooperation (ENABEL), formerly the Belgian Administration for Development and Cooperation) cofinanced two significant initiatives: The Kagera Community Development Programme (KCDP) for five years from 1997 to 2003 and the Sustainable Improvement of Banana Cropping System (2009–2013) (Weerdt, 2003; Gallez et al., 2004).

KCDP was pivotal in introducing, propagating, demonstrating, and disseminating better-performing banana varieties (high-yielding, bigger bunch sizes, shorter maturation periods, tolerant to pests and diseases, and drought) called "Superior Banana Varieties" (SBVs). The program facilitated the importation of approximately 71,000 in vitro plants from 25 different high-yielding, disease-resistant varieties known as "Superior Banana Varieties" (SBVs). SBVs primarily comprise FHIA hybrids (e.g., FHIA 17, FHIA 23, FHIA 25, SH3436-9, SH3640), exotic landraces (Yangambi KM 5, Saba/Cardaba, Pelipita), and some IITA improved varieties. The FHIA hybrids were part of the International Musa Testing Programme (IMTP) coordinated by the International Network for the Improvement of Banana and Plantain (INIBAP) (Gallez et al., 2004). Various organizations (e.g., TARI-Maruku, formerly known as ARDI-Maruku, local authorities, NGOs, schools, and religious groups) and progressive farmers participated in the establishment of nurseries, the multiplication of planting materials, on-farm testing, and the distribution of planting materials to smallholder farmers from 1997 to 2002 (Nkuba, 2007). FHIA 17 and FHIA 23 (cooking banana), FHIA 25, and Yangambi KM 5 (beer banana) were disseminated widely (Swennen et al., 2013). By 2003, when the KCDP ended, an estimated 2.5 million banana suckers of SBVs had been distributed directly to smallholder farmers in the Kagera Region from the project's multiplication fields, facilitating the indirect distribution of 4 million banana suckers through a farmer-to-farmer approach (KCDP, 2003). Various studies have indicated that SBVs, such as FHIA 01, Yangambi KM 5, Pelipita, SH3436-9 (Shilingi/Nyoroba), FHIA 17, and FHIA 23, performed better than the landraces (Weerdt, 2003).

The Sustainable Improvement of Banana Cropping System project consolidated the program's progress by strengthening institutional capacities and dissemination efficiency of the SBVs selected by farmers during KCDP for their higher productivity and tolerance to pests and diseases.

TARI has continued its efforts to improve banana varieties, recently releasing four improved banana varieties that are suited to local agroecological conditions and preferences (Madalla et al., 2022). These are referred to as TARIBAN 1, TARIBAN 2, TARIBAN 3, and TARIBAN 4.

Despite the tremendous investments and widespread dissemination of SBVs for nearly 25 years, both directly and indirectly (farmer to farmer), through KCDP, followed by the Sustainable Improvement of Banana Cropping System, there is scant, systematically documented information on the context surrounding SBV adoption, adoption rates, determinants of adoption, and their socioeconomic impacts in the region.

In late 2024, we conducted an adoption and impact study in two phases. The first phase aimed to understand the technological, biophysical, and socioeconomic contexts of SBV adoption in Kagera, based on focus group discussions (FGDs) with farmers and key informant interviews (KIIs) with value chain actors and stakeholders. The second phase aimed to quantify the adoption rate of SBVs and their socioeconomic impact based on household survey data.

The report is structured into four sections. The next section presents qualitative and quantitative data collection and analytical research methods. Section 3 presents descriptive and model estimation results, focusing on adoption determinants and the impacts of adoption on banana productivity and household food security, as well as its direct contribution to Kagera's economy. Section 4 concludes and draws implications for the current banana breeding program.

Study methods

Qualitative data collection

The qualitative method involved FGDs with smallholder banana farmers and KIIs with banana value chain actors (e.g., processors and traders), as well as stakeholders (e.g., extension workers, researchers, development practitioners, and local authorities).

The FGDs involved 12 focus groups, each with 8–12 households (141 FGD participants) covering six wards and 12 villages across six districts. The FGD participants discussed Kagera's banana production system, socioeconomic and institutional contexts, and outcomes of banana improvement interventions. They described the technological characteristics (e.g., desirable trait preferences of varieties), as well as socioeconomic and farmer characteristics (e.g., awareness, access, availability, resources, markets, disease/pest, and soil fertility) that influence the adoption and perceived outcomes of the interventions. Furthermore, they highlighted the significance of the banana crop for food security, household division of labor, decision-making, and production constraints.

The KIIs involved 14 banana processors (e.g., local beer and wine, roasted banana food [e.g., noodles, banana crisps and chips, biscuits] makers), and 19 banana traders (11 retailers, five wholesalers, and three intermediary traders), and 11 stakeholders from the district and ward extension services, research institutions (TARI-Maruku), and local authorities.

The FGDs and KIIs helped to understand better the needs, knowledge, practices, and behaviors of banana value chain actors, as well as identify the interplay of factors that enable or hinder the adoption of SBVs (e.g., technological characteristics, user acceptance, and biophysical and socioeconomic considerations), and the perceived outcomes of SBVs. The results informed the design of a standardized household survey tool for the adoption and impact assessment of improved banana technologies in the region.

Quantitative data collection

The quantitative method involved a standard household survey with randomly selected banana farmers. The survey covered eight districts of Kagera, which have 445,018 banana-producing households (URT, 2021), and captured the variability in pest and disease prevalence and banana farming systems within the region, with implications for adopting SBVs. Some districts (e.g., Biharamulo) are much drier and more maize-based than banana-based farming systems (Figure 1 and Table 1).

In calculating the sample size, we applied power analysis to ensure a sufficient chance of detecting a statistically significant effect on our outcome variable: productivity. Using a two-sided test with a 5% level of significance, power (80%), and effect size (ES) of 0.0975 (equivalent to 0.28 ton per ha), which represents a meaningful difference in the population, we calculated the desired sample size to be 1,240, adjusting for the expected response rate.

We employed a multistage sampling strategy that combined purposive and random sampling. We employed the purposive sampling method to select four wards, and the random sampling method to select villages and households in two stages. In the first stage, we selected 120 villages from the four wards using the probability proportional to size (PPS) technique, as the villages have different population sizes. Larger villages have more than one cluster. In the second stage, we randomly selected 1,240 households in the selected villages, with a fixed number of households per cluster.

Table 1. Number of sampled households by district.

District	Number	%
Bukoba District Council	193	15.6
Bukoba Urban	74	6.0
Missenyi District Council	111	9.0
Muleba	325	26.2
Kyerwa	211	17.0
Ngara	170	13.7
Biharamulo	94	7.6
Karagwe	62	5.0
Total	1240	100.0

The sampled farmers provided primary data on household demographics and farm characteristics, banana production practices, banana plot characteristics, varieties grown, area under improved variety cultivation, total area of banana cultivation, methods of acquiring planting materials, pest and disease prevalence and management, consumption, and sale of bananas, yield levels, and food security status. Additionally, we compiled secondary quantitative data on regional banana production and prices.

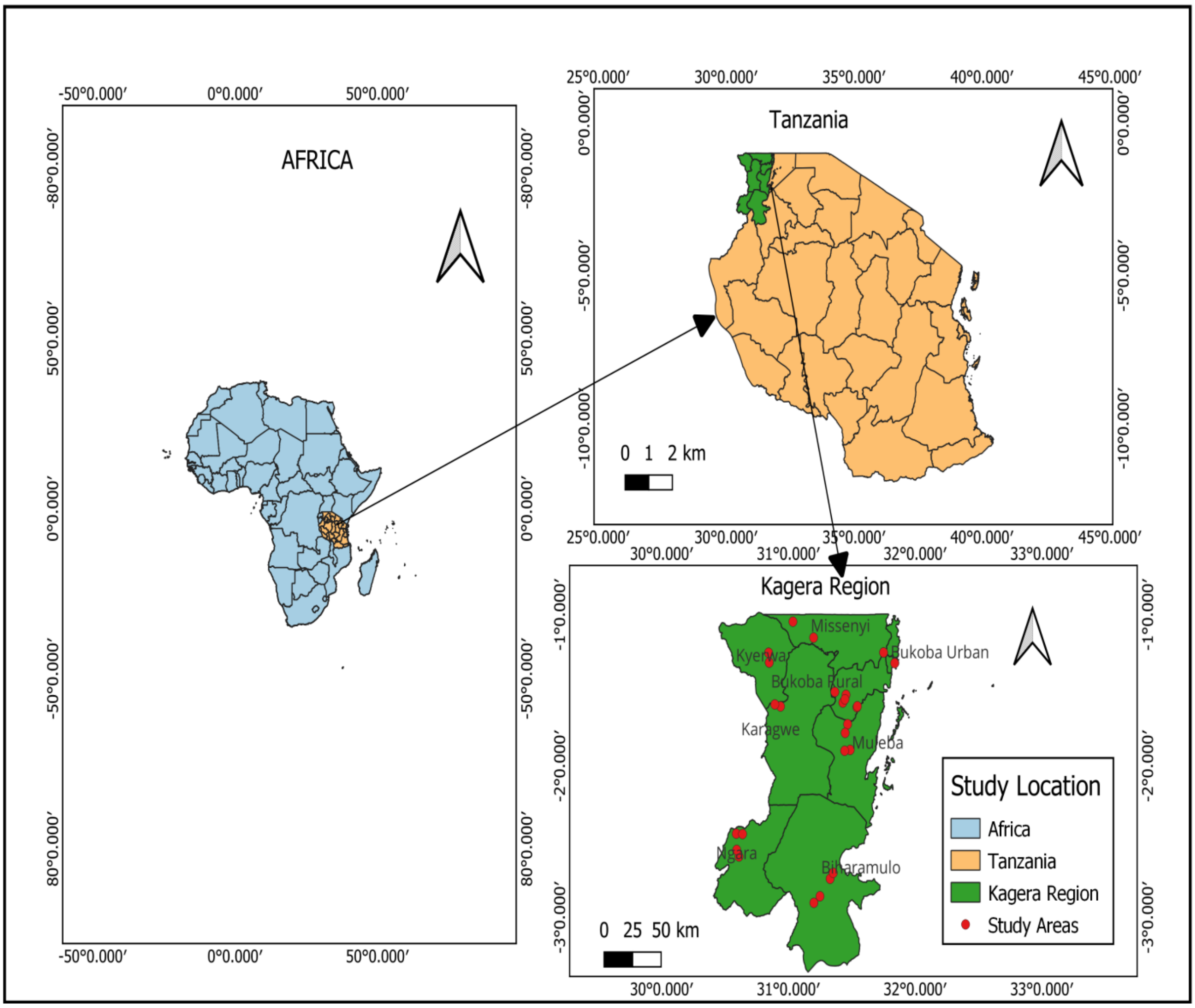

Figure 1. Map of the study areas in Kagera region.
Note: Figure 1 was created using QGIS 3.26.2 software, incorporating coordinates collected during the survey through the GPS locator feature embedded in the *SurveyCTO* CAPI tool. The Figure includes two shapefiles: one of Africa and another of Tanzania. First, the existing Africa shapefile was imported into QGIS to display African countries and to locate the area of interest—Tanzania. Then, the Tanzania shapefile was imported to display the Kagera region, where the study was conducted, along with its district boundaries. Finally, the exact GPS coordinates collected from the study areas (villages) were added to the map to indicate the specific locations of the study.

Description and measurement of treatment and independent variables

The treatment variable is the adoption of SBVs. Given that a quarter of a century has passed since the introduction of SBVs in the region, the decision to adopt SBVs has become more stable. Consistent with Edmeadeset et al. (2007), an SBV adopter is defined as one who reported cultivating at least one SBV in 2024. The independent variables are a set of demographics, socioeconomic, biophysical, and institutional characteristics of the sample households. The demographic variables include household size, sex, age, educational level, and marital status of the household head. Given the need for knowledge acquisition and the information-intensive nature of the adoption decision-making process, farmers with a higher level of education are better equipped to obtain and process information and become aware of the benefits and risks associated with SBVs. Age can influence responsiveness to new technologies, such as the SBVs. Younger and senior farmers respond differently to new technologies. Sex can represent the institutional and cultural limitations regarding household decision-making. Household size, as measured by the number of family members in the household, represents the labor force available to cultivate bananas, thus influencing the decision to adopt new technologies.

The socioeconomic variables, including livestock holdings (measured in Tropical Livestock Units [TLU]), banana land size, savings, access to off-farm employment, and assets (such as bicycles, motorbikes, radios, and televisions), are indicators of resource endowment that may influence a household's willingness to take risks with new technologies and decide on adopting SBVs.

The institutional variables include access to extension, credit services, training, and group membership in farmer associations. Access to extension services, training, and group membership exposes households to more information and learning opportunities, thereby increasing their chances of learning about new agricultural technologies and adopting them. Credit access enables farmers to afford the costs associated with adopting technology. Phone ownership may influence farmers' adoption decisions by reducing transaction costs and improving mobility.

Biophysical factors include elevation and geographical location. Elevation is related to adoption through its effects on soil fertility, disease, and pest pressure, which are influenced by temperature and humidity that vary with elevation. The study areas are delineated into two zones: mid-altitude, defined as below 1500 masl and high altitude, defined as above 1500 masl. Location is represented by districts used to capture the influence of district-specific characteristics in SBV adoption.

Description and measurement of outcome variables

The study has two outcome variables: banana productivity, measured by banana yield (ton/ha/year), and food security, measured by per capita calorie consumption and per capita household income. Measuring food security is a function of four dimensions: availability, access, utilization, and stability. However, it is challenging to capture all four dimensions. Additionally, physical availability and accessibility overlap significantly in rural areas, where markets often do not function effectively, making it challenging to distinguish between them (Pieters et al., 2013). In Kagera, where markets are not considered to function efficiently, bananas are primarily grown for on-farm consumption, providing the bulk of energy and nutrients. In such regions, a banana-growing household can have a low income, falling below the 3 USD per day international poverty line, yet still be food secure because the household prioritizes on-farm consumption over sales to ensure its own food security. Hence, using income alone may not be an adequate indicator of food security. Similarly, per capita calorie consumption serves only the availability dimension (i.e., the physical presence of sufficient food) and the access dimension (people's ability to obtain food through physical means) of household food security. Both indicators also overlook other dimensions of food security, including utilization (the body's ability to utilize the nutrients from food, which depends on hygiene, sanitation, and preparation) and stability (the ability to have consistent access to food over time). In this study, we use both indicators—per capita household income (in USD) and per capita calorie consumption—to proxy the availability and access dimensions of food insecurity.

We use per capita income levels relative to the international poverty threshold. The World Bank has recently announced a new international poverty line of 3 USD per day (2021 Purchasing Power Parity, or PPP). A person earning below 3 USD a day is considered poor. Household food insecurity is defined relative to the recommended daily energy requirements (2,100 kcal/person/day). According to the FAO, an individual is considered food insecure if they subsist on a dietary energy level of 2,100 kcal per day or less, i.e., the food insecurity line (FAO, 2004). The study uses the three Foster, Greer, and Thorbecke (FGT) indices of poverty and adapts them to food insecurity (Foster et al., 1984). These are the headcount index, food insecurity gap index, and food insecurity gap squared index. The headcount ratio measures the incidence of food insecurity, which is the proportion of people living below the minimum dietary energy requirement. The food insecurity gap index measures the depth of food insecurity, which is the extent of income shortfall from the food insecurity line. The food insecurity gap squared index measures the severity of food insecurity, indicating the degree of consumption inequality among households experiencing food insecurity.

Descriptive data analysis

We conduct a descriptive analysis using contingency tables to assess the association between two variables of interest within specific groups or contexts using the chi-squared test of independence. The chi-squared test of independence shows whether an effect exists between two categorical variables. While the chi-squared test of independence proves useful to test whether an effect exists, it does not measure the effect size (i.e., the strength of the relationship). We use the odds ratio to measure the effect size for categorical variables of interest.

Empirical model

As our data is observational, SBV adoption is not random, but rather a choice made by banana farmers based on both observable and unobservable factors. These unobservable factors (e.g., motivation) are captured by the error term in the selection (or adoption) equation. If these same unobservable factors also affect the outcome variable (e.g., yield), the error term of the adoption equation can be correlated with the error terms of the outcome equations. The failure to address this correlation may result in biased parameter estimates that do not accurately reflect the true relationship between adoption and the outcome variables.

Following several studies (e.g., Tufa et al., 2019; Manda et al., 2019; Ainembabazi et al., 2018; Abdoulaye et al., 2018; Wossen et al., 2017; Alene and Manyong, 2006), we employ an econometric model called the endogenous switching regression (ESR) to assess the impacts of SBV adoption on SBV productivity, per capita household income, and per-calorie consumption. The ESR model consists of the adoption or selection equation (probit model), which determines which regime a sample banana-growing household belongs to, given as:

$$A^* = X'\beta + \mu \qquad (1)$$

Where A^* is a latent variable representing the adoption decision; X is a vector of observed household and farm characteristics; β is a vector of unknown parameters to be estimated; and is the error term.

The ESR model also consists of two separate linear equations of an outcome variable, conditional on A_i, specified in two regimes: (2a) and (2b).

$$\text{Regime 1} \quad Y_{1i} = \beta_1 X_{1i} + \varepsilon_{1i} \qquad if \quad A_{1i} = 1 \qquad (2a)$$

$$\text{Regime 2} \quad Y_{2i} = \beta_{2i} X_{2i} + \varepsilon_{2i} \qquad if \quad A_{1i} = 0 \qquad (2b)$$

where Y_{1i} and Y_{2i} are the values of the outcome variable observed for each household, depending on the selection criterion A_i equation; X_i represents a vector of exogenous variables that influence the outcome variables; β is a vector of parameters to be estimated; ε_{1i} and ε_{2i} are the error terms associated with the two equations of the outcome variable.

Eq. (1) is estimated to model the adoption decision process that leads to sorting into two regimes or groups. The expected values of the error terms, ε_1 and ε_2, of the outcome equations, conditional on the selection equation, are nonzero because of the possible correlation between the error term in the selection equation and the error terms of the outcome equations (Eq. 3a and Eq. 3b).

$$E(\varepsilon_{i1}|A_i = 1) = \sigma_{\boldsymbol{u\varepsilon_1}} \frac{\phi(\hat{A})}{\Phi(\hat{A})} \qquad (3a)$$

$$E(\varepsilon_{i2}|A_i = 0) = \sigma_{\boldsymbol{u\varepsilon_2}} \frac{\phi(\hat{A})}{1-\Phi(\hat{A})} \qquad (3b)$$

where $\phi(.)$ is the standard normal probability density function, $\Phi(.)$ is the standard normal cumulative function; $\frac{\phi(\hat{A})}{\Phi(\hat{A})}$ and $\frac{\phi(\hat{A})}{1-\Phi(\hat{A})}$ are the inverse Mills' ratio evaluated at $\hat{A} = Z_i\gamma$ in the selection (adoption) equation where $\hat{A}$ is the predicted probability of adoption, A_i.

As the ESR model addresses the issue of selection bias as a missing variable problem, the inverse Mills' ratio terms from the selection equation (the probit model) are added into the outcome equations to correct for endogeneity and potential selection bias in the second stage (Maddala, 1986) as:

$$\mathrm{Y_{1i}} = \upbeta_1 \mathrm{X_{1i}} + \sigma_{\mathrm{u}\varepsilon_1} \frac{\phi(\hat{\mathrm{A}})}{\Phi(\hat{\mathrm{A}})} + \varepsilon_{1i}, \ \text{if } \mathrm{A_i} = 1 \qquad (4a)$$

$$\mathrm{Y_{2i}} = \upbeta \mathrm{X_{2i}} + \sigma_{\mathrm{u}\varepsilon_2} \frac{\phi(\hat{\mathrm{A}})}{1-\Phi(\hat{\mathrm{A}})} + \varepsilon_{2i}, \ \text{if } \mathrm{A_i} = 0 \qquad (4b)$$

The inclusion of the inverse Mills' ratio terms from the selection equation (Eq.1) ensures the consistency of the parameter estimates in the outcome equations by correcting for the correlation between the error terms of the selection and outcome equations. Eq. (4a) and Eq. (4b) can be estimated in a two-stage procedure. However, an efficient way of estimating them is using Full Information Maximum Likelihood (FIML), which estimates the average treatment effects on the treated (ATT) (Lokshin and Sajaia, 2004). The ATT represents the average impact of adopting SBVs on adopters.

Results and discussion

Contexts

Banana varieties

Bananas are the most important staple crop for household food security in Kagera, as reported by 68% of the respondents, followed by maize at 26% and cassava at 5% (Figure 2). Farmers cultivate endemic landraces, exotic landraces, and FHIA hybrids, as well as other hybrids developed through collaborative efforts among IITA, NARO, and TARI, including TARIBAN 1, TARIBAN 2, TARIBAN 3, and TARIBAN 4. Endemic landraces (e.g., Nshakala, Nyoya, Ntobe, Nshasha, Nchoncho, Mbwailuma/Mbwazirume) are the EAHBs that have been cultivated in Kagera for centuries and are locally known as Matooke. Exotic landraces are varieties introduced from neighboring countries and other regions of Tanzania. Exotic landraces include Gonja, Njoge (also known as Gros Michel), Mavubo, Kivuvu, Mpologoma, Yangambi KM 5, and Ndizi Sukari. The FHIA hybrids, introduced to Kagera through the KCDP program in 1997, include FHIA 17, FHIA 23, and FHIA 25.

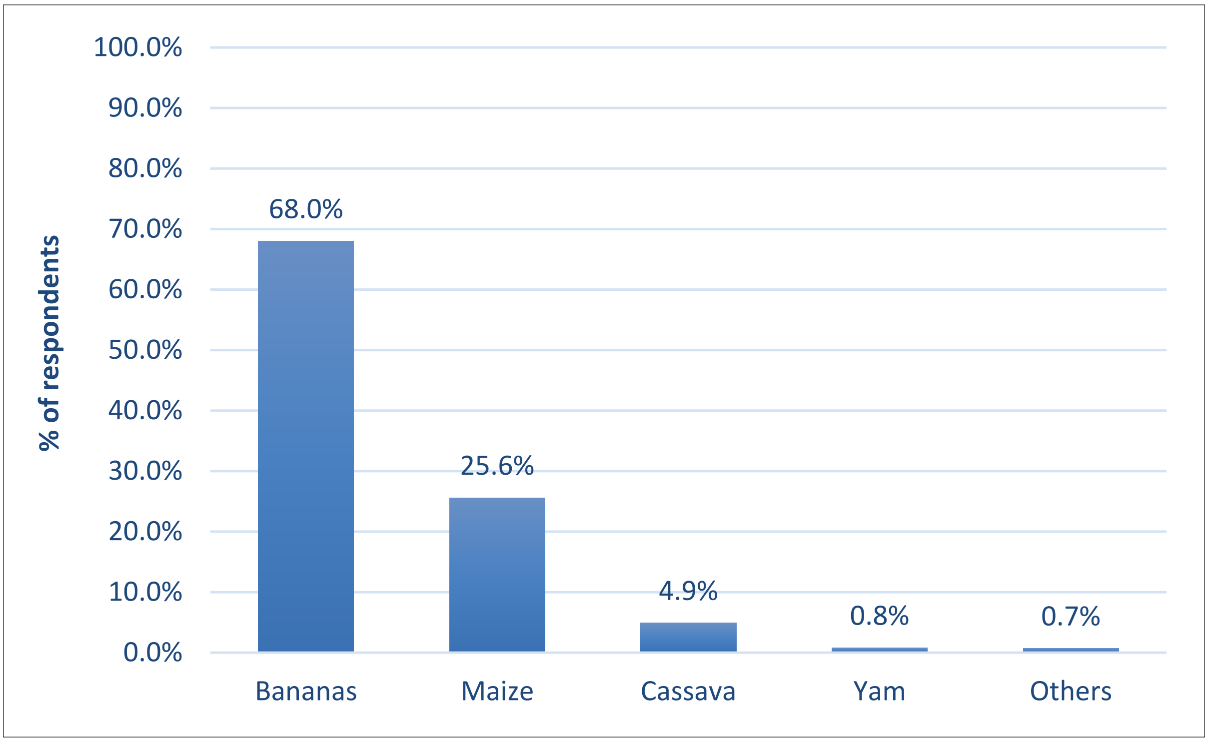

Figure 2. Major staple crops for food security in Kagera region.

Sources of information and planting materials

The FGD participants reported that they became aware of SBVs primarily through interactions with fellow farmers and neighbors. Additionally, they relied on on-farm trials, demonstration plots, and farmer field schools managed by research institutes (TARI-Maruku) and extension services. Fewer farmers accessed information from cooperatives or farm associations.

Fellow farmers and neighbors were also the primary source of planting materials. They received banana planting materials as gifts from fellow farmers (relatives/friends/neighbors). This emphasizes the critical role of peer-to-peer social networks in disseminating planting materials and information about SBVs. Some reported purchasing from fellow farmers and sourcing from research institutes (TARI-Maruku/MOA).

Farmers’ preferences for SBVs

Farmers utilize bananas in various ways, including cooking, brewing, making desserts, and roasting. FGD participants identified FHIA 17, FHIA 23, FHIA 25, Yangambi KM 5, Pelipita, and Shillingi as the preferred varieties based on several traits, including big bunch, marketability (fetching a high price), adaptability to poor soil fertility conditions (not requiring heavy application of manure), tolerance to diseases/pests, producing many suckers, and early maturity in the same order of importance. Other traits mentioned by a few farmers include taste, firm anchorage of the soil (resistance to wind lodging), being highly valued for cultural ceremonies (e.g., weddings, funerals), and requiring less labor. These results guide the selection of traits to consider in the breeding program.

FHIA 17 is the preferred SBV, followed by FHIA 23, Yangambi KM 5, FHIA 25, and Pelipita. Shillingi is the least preferred variety. For instance, FHIA 17 and FHIA 23 are predominantly used for cooking. They can also be used as a dessert and in beverages, and processed with cassava flour to produce a local snack known as *vibago*, which is processed and sold by most processors around local markets and roadsides. FHIA 25 and Yangambi KM 5 are primarily used for beverages, although Yangambi KM 5 is also used as a dessert ingredient. FHIA 25 and Yangambi KM 5 are dominant beverage varieties due to their similar feature of producing a large amount of juice when processing.

Banana processors’ preferences

The processors’ preferred varieties for local beer making are Yangambi KM 5 and FHIA 25. They prefer Yangambi KM 5 for winemaking, and Kyayaya and Cardaba for producing roasted bananas and snacks (Figure 3). They reported shifting toward using SBVs for banana products due to their superior qualities, including ease of peeling, a longer shelf life, and a higher juice yield. They suggested increasing the sugar content for FHIA 25 and Yangambi KM5 varieties, a larger finger size for Cardaba, extending the shelf life of Yangambi KM5, and improving the taste of SBVs.

Left: Banana wine; Right: Banana snacks.

Figure 3. Banana products.
(Photo credit to IITA)

Banana traders' preferences

SBVs and landraces are widely traded, with landraces being the most popular among locals and SBVs among customers in distant markets. Landraces, such as Nsikila, Nshakala, Ntobe, and Njoge*,* dominate the local market because most local consumers prefer the landraces over the SBVs. Appearance, bunch size, and finger size, as well as a sweeter taste, are key considerations in purchase decisions.

Banana trade

Banana traders (wholesalers and intermediaries) primarily deal with fresh SBVs, and most are involved in the trade of SBVs. Unlike the endemic landraces, the SBVs produce large fingers and bunch sizes, making them highly marketable and commanding the highest possible prices. As a result, they are in high demand as a dessert in urban markets outside Kagera, driven by the large fruit size of the variety that attracts customers. While SBVs are versatile for cooking, roasting, and as a dessert, their main appeal in distant urban markets is as a dessert fruit.

In most cases, farmers transport their bananas from their farms to banana collection centers in the market using motorcycles (Figure 4), where traders gather to purchase ready-to-transport bananas for distribution to destination markets. They aggregate bananas at market centers (like Katoma banana market center) (Figure 5) and transport them on trucks and ships to various regions of the country, such as Geita, Shinyanga, Tabora, Mwanza, Dodoma, and Dar-es-Salaam (Figure 6 and Figure 7).

Figure 4. Boda carrying bunches from the farmer's field to the collection point in the market.
Photo credit: IITA

Figure 5. Banana collection point in the market.
Photo credit: IITA

Figure 6. Truck carrying SBVs from Kagera to Dar-Es-Salaam.
Photo credit: IITA

Figure 7. SBVs shipped to big markets in Mwanza, Shinyanga, and Dar-Es-Salaam via Lake Victoria.
Photo credit: IITA

Banana farmers' constraints

Banana farmers face critical constraints, including disease and pest incidence, low soil fertility, drought or moisture stress, small farmland sizes, a lack of knowledge of improved agronomic and crop protection practices, limited access to agricultural inputs, and a shortage of healthy planting materials (Figure 8).

These constraints can be grouped into biotic and abiotic. Biotic constraints, especially disease and pest incidence, and a lack of knowledge about improved agronomic and crop protection practices, negatively affected the adoption of SBVs. The FGD participants reported abandoning some varieties due to their high susceptibility to pests and diseases, low yield (resulting in small bunches or fingers), low adaptability to poor soils and drought/moisture stress, low market demand, and poor taste (inadequate suitability for cooking, roasting, brewing, and juice making). They no longer cultivated some landraces due to high mat disappearance caused by high susceptibility to pests and diseases. Susceptible varieties, such as Njoge, Mchare, Sukari ndizi, and Pisang Awak (Kayinja), are not common in the region. Some participants also reported that they no longer cultivated some FHIA hybrids (e.g., FHIA 01) and Shillingi primarily due to their low yield, specifically small bunches and fingers.

The lack of agronomic knowledge is evident, as improved agronomic practices are notably absent. For example, farmers place bananas in cool areas, such as on thatched roofs at night or in places that allow for cool conditions, as part of postharvest management techniques to increase the shelf life of harvested banana bunches. Most of the farmers use traditional practices, including desuckering, denavelling, mattocking, intercropping, hand-weeding, mulching, and propping. Desuckering (removal of surplus and unwanted suckers from the mother banana plant) improves the supply of nutrients to the main plant, which later produces the banana bunch. Denavelling (removal of the male bud or navel after the female phase or once bunch formation is complete) also reduces nutrient competition, ensuring sufficient resources for fruit development, improves fruit quality and size, and prevents disease infection and pest infestations. Mattocking (the removal of the banana pseudostem after harvesting the fruit) is crucial for recycling nutrients and maintaining field sanitation. Removing the pseudostem also creates space, allowing for better nutrient flow and the growth of new suckers. Farmers typically intercrop bananas with coffee, while some also grow crops like cassava around the banana fields. When banana plants are still young, they are intercropped with maize and beans. Banana producers never practice chemical fertilizer use, as it is considered a significant cause of disease outbreaks and "yield decline" (i.e., loss of soil fertility). Farmers' negative attitude towards the use of chemical fertilizers in banana fields dates back decades.

Market-related constraints (e.g., a lack of access to inputs, market information, and low prices due to broker interference) are prominent. Large-scale traders receive the highest share of gross marketing margins, followed by retailers, small-scale traders, and farmers (Nkuba, 2007). These findings underscore the importance of training and extension services that focus on good agronomic practices, pest and disease management, and banana husbandry to enhance the productivity and resilience of banana farming systems in Kagera.

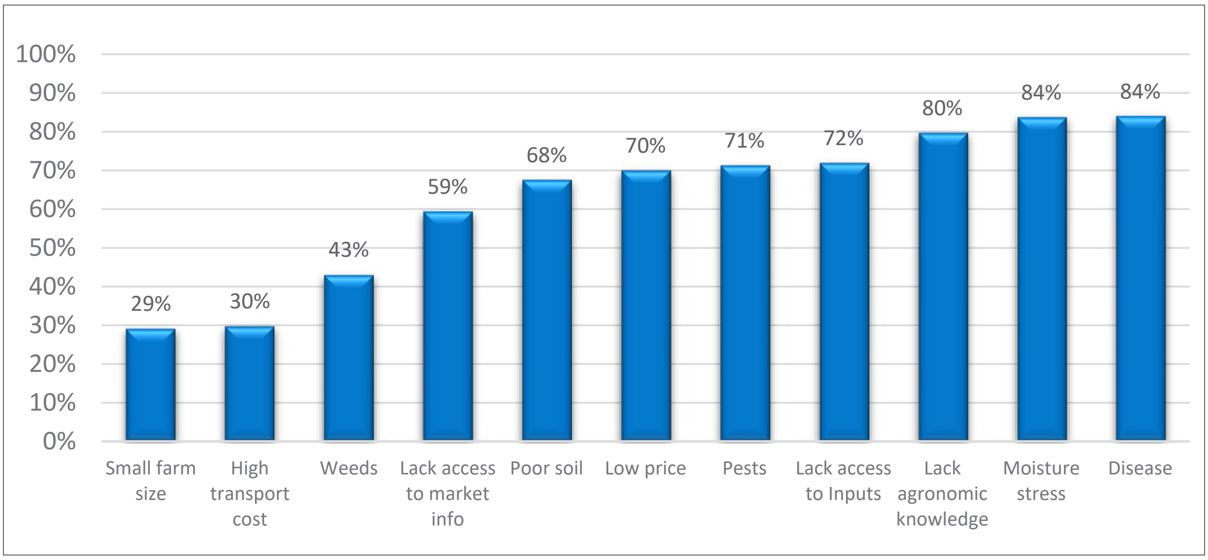

Figure 8. Percentage of farmers constrained by different factors.

Bivariate relationships between adoption and intermediate outcomes

Adoption and banana disease and pest incidence

Respondents identified three types of banana diseases (Fusarium wilt [also known as Panama disease], Sigatoka, and Xanthomonas wilt) and pests (weevils and nematodes) in their plantations based on a set of pictures. They perceive that SBVs are superior to the local varieties in terms of yield and resistance to diseases/pests such as Sigatoka and weevils. The adoption of SBVs was systematically associated with a decrease in the incidence of the three diseases. Approximately 61% of respondents reported experiencing Fusarium wilt, with a lower incidence among adopters than among nonadopters (Figure 9). About 53% of adopters experienced Fusarium wilt compared to 68% of nonadopters, indicating that the odds of an adopter being vulnerable to Fusarium wilt are half as high as those of a nonadopter [χ^2(1) =29.8, p< 0.01]. Alternatively, nonadopters are nearly twice as likely to experience Fusarium wilt as adopters.

Similarly, fewer adopters were affected by Sigatoka and Xanthomonas wilt than nonadopters. About 31% of adopters experienced Sigatoka, compared to 44% of nonadopters, indicating that the odds of an adopter being vulnerable to Sigatoka are half as high as those of a nonadopter [χ2(1) = 24.1, p < 0.01]. Furthermore, approximately 58% of adopters experienced Xanthomonas wilt, compared to 66% of nonadopters, indicating that the odds of an adopter being vulnerable to Xanthomonas are 0.7 times those of a nonadopter [χ2 (1) = 9.3, p < 0.01]. Among the introduced SBVs, Saba and Cardaba (locally known as Shubiri) are susceptible to Fusarium wilt. Yangambi KM 5 is tolerant to all common pests and diseases (weevils, nematodes, Sigatoka, and Fusarium wilt).

Regarding pests, about 70% and 27% of households reported experiencing weevils and nematodes, respectively. However, there were no statistically significant differences in the percentage of adopters and nonadopters experiencing pest incidence. Adopters and nonadopters are equally affected by pests.

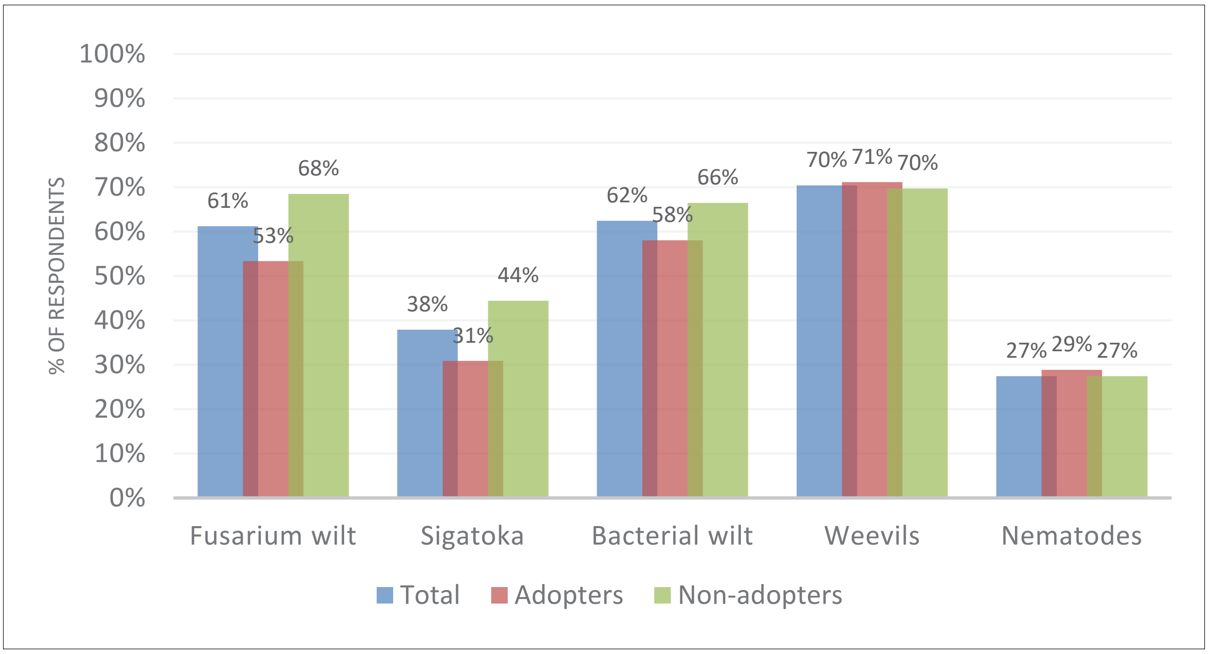

Figure 9. Percentage of adopters and nonadopters experiencing diseases and pests.

Banana production status

Nearly 70% of households produce surplus bananas, with statistically significant differences in the proportion of adopters and nonadopters (Figure 10). Approximately 74% of adopters are surplus producers, compared to about 64% of nonadopters, indicating a statistically significant association between adoption and surplus production [χ2(1) = 21.7, p < 0.01]. Adopters are 1.6 times more likely to be surplus producers than nonadopters.

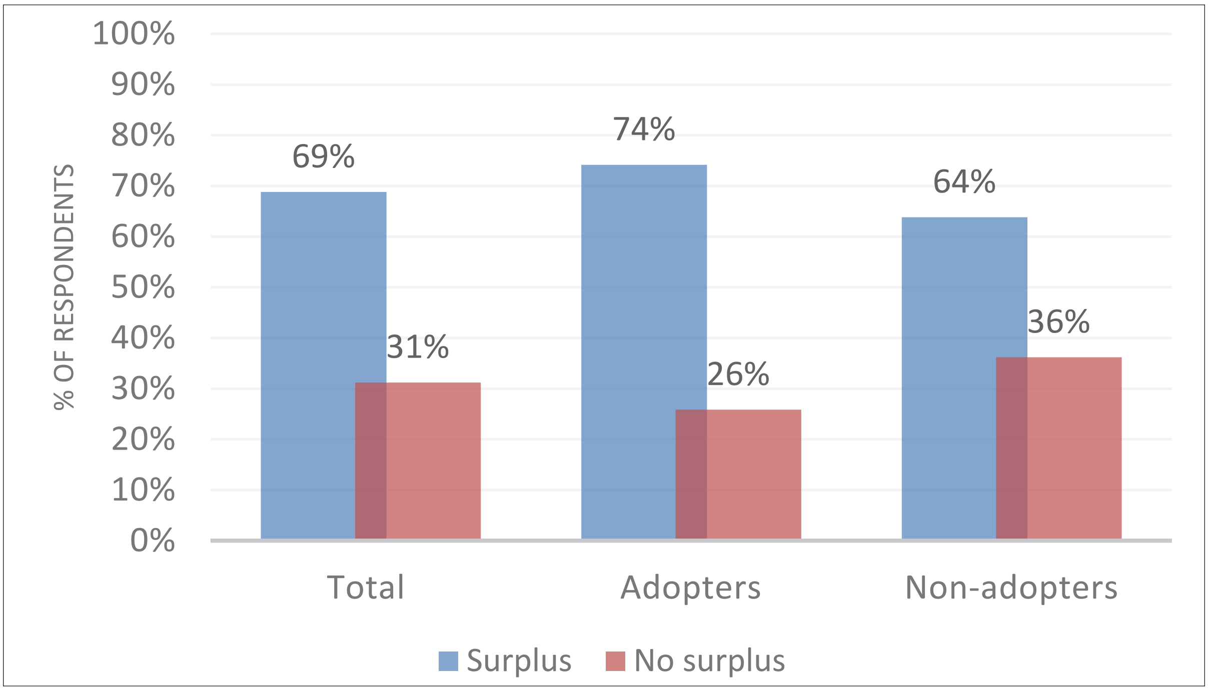

Figure 10. Percentage of adopters and nonadopters producing surplus bananas.

Adoption and income generation

Table 2 shows that about 60% of the respondents reported cultivating bananas primarily for their own consumption, with a slight difference in the percentage of adopters and nonadopters. Cultivating bananas for home consumption is just as important for nonadopters as it is for adopters. In contrast, there is a statistically significant difference in the proportion of adopters and nonadopters cultivating bananas primarily for income generation [$\chi^2(1) = 130.0$, $p < 0.01$]. A quarter of respondents (24.6%) reported cultivating bananas primarily for income generation, with 39% of adopters compared to 11% of nonadopters. Adopters are five times more likely to cultivate bananas for income generation than nonadopters.

Table 2. Banana cultivation for home consumption vs. cash income generation.

Primary purpose of banana cultivation	Total (%)	Adopters (%)	Nonadopters (%)	Chi-square
Primarily for own consumption (1 = yes)	60.3	62.4	58.4	2.10 ns
Primarily for income generation (1 = yes)	24.6	39.1	11.2	130***

ns not significant and *** p<0.01

Banana sales

Three-fourths of the respondents reported selling bananas in the 2023/24 season, with a relatively higher proportion of adopters compared to nonadopters (Figure 11). About 84% of adopters sold bananas in the 2023/24 season compared to about 66% of nonadopters, suggesting a systematic association between adoption and banana sales [$\chi^2(1) = 48.9$, $p < 0.01$]. Adopters are 2.6 times more likely to sell bananas than nonadopters.

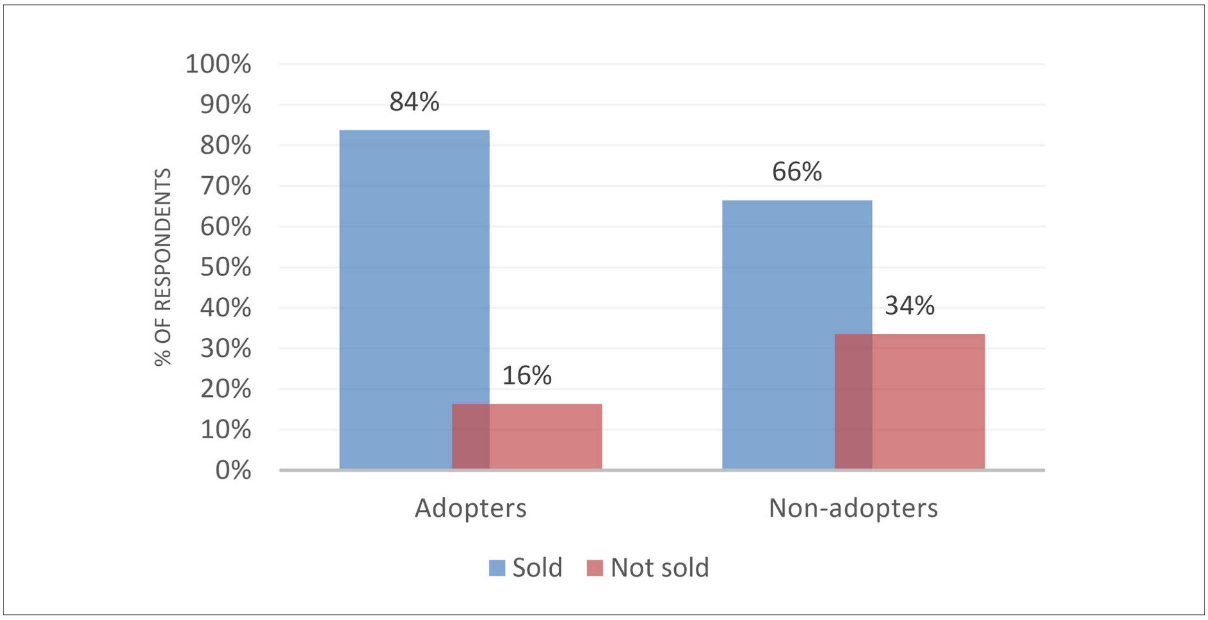

Figure 11. Banana sales by adoption status.

Shares of bananas in home consumption vs. sales

The magnitude of banana consumption highlights the critical role of bananas in household food security, with approximately 63% of the bananas produced allocated for household consumption, compared to 26.5% sold to generate income (Figure 12). The remaining portion is shared as gifts or goes to waste. There are differences between adopters and nonadopters in the percentage of banana output used for home consumption and sales. Adopters allocate 59% of their banana production to household consumption, while nonadopters allocate two-thirds (67%) of their banana production to the same purpose. While bananas are important for both adopters and nonadopters as a source of income after coffee, a higher percentage of the former (49%) consider them more important than the latter (40%). Adopters allocate 30.6% of their banana outputs for sale, compared to 23.2% used by nonadopters for the same purpose. The difference is statistically significant (t =7.4, p< 0.01).

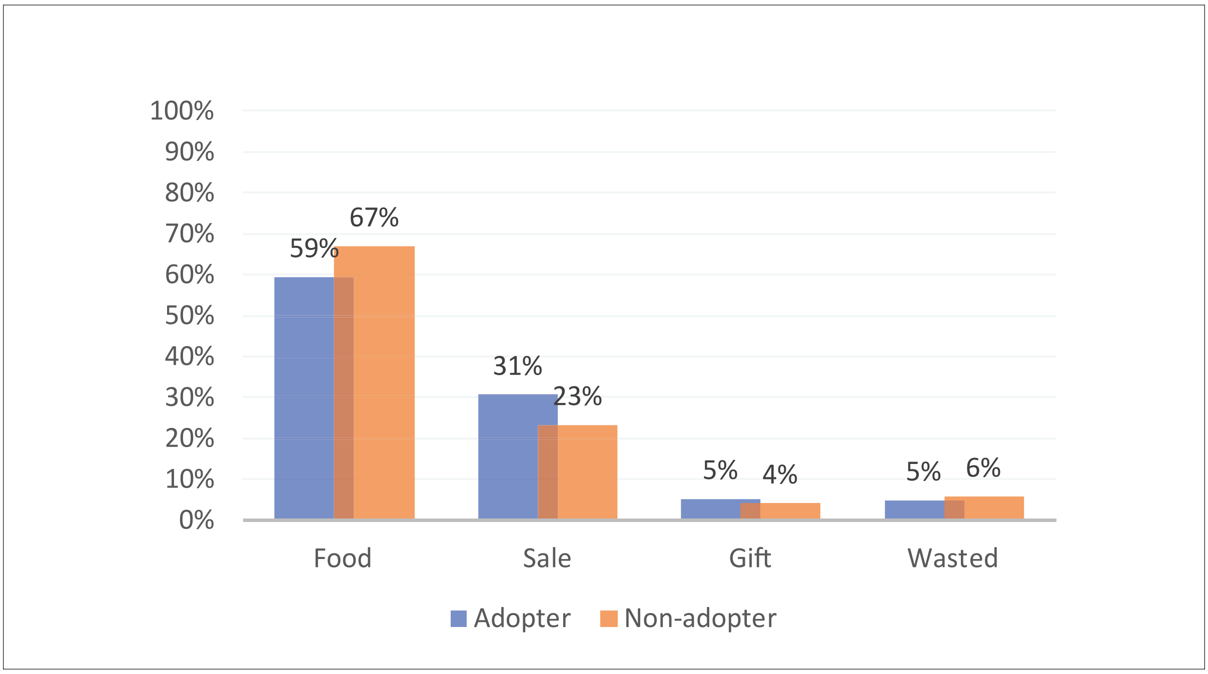

Figure 12. Shares of banana production for home consumption and sale by adoption status.

Household decision making

Men predominantly decide on the sales of all types of bananas—including cooking, roasting, dessert, and beverage sales—with minimal joint decision-making or involvement from women. This division highlights the traditional gender roles in agriculture, where men oversee economically impactful decisions while women are often relegated to supporting roles. However, there is a systematic association between adoption and women's decision-making, regardless of the type of banana. The participation of women in decisions related to banana sales is higher among adopting households than among nonadopting households. A fifth of the respondents reported that wives decide on cooking banana sales, with a relatively higher proportion in the adopter group than in the nonadopter group. In the adopter group, 23% of women decide to sell bananas, compared to 18% in the nonadopter group (Table 3). The difference is statistically significant [$\chi 2$ (1) = 9.0, $p < 0.05$]. Women in the adopter group are 1.3 times more likely to make decisions than nonadopters. We found similar results with banana types used as desserts and in beverages. That is, the women in the adopter group are more likely to make sales decisions than those in the nonadopter group.

Table 3. Household decision-making on banana sales (%).

Variables	Total	Adopter	Non-adopter	Chi-square
Decision on sales				
Cooking bananas				
wife (1 = yes)	20.6	22.9	18.3	9.0**
Dessert bananas				
wife (1 = yes)	16.2	19.5	13.2	20.4***
Beverage bananas				
wife (1 = yes)	11.7	15.8	7.9	21.8***

*** p<0.01; ** p<0.05

Descriptive results

Adoption rates

SBVs include three FHIA hybrids (FHIA 17, FHIA 23, FHIA 25), as well as other hybrids developed through collaborative efforts among IITA, NARO, and TARI (TARIBAN 1, TARIBAN 4, introduced since 2021), and exotic landraces (Cardaba, Pelipita, Yangambi KM 5). Figure 13 shows the adoption rate by variety. Although over 20 SBVs were introduced into the region, farmers adopted one or two varieties for cooking (e.g., FHIA17 and FHIA23) and two varieties for beverage making (e.g., Yangambi KM 5 and FHIA25). Farmers are more interested in a few varieties with multiple purposes than in multiple varieties with a single trait, which should guide the breeding program. The adoption rate of SBVs in 2024 was 48%, with FHIA 17 (24.9%) being the most prevalent, followed by FHIA 23 (6.6%) and FHIA 25 (3.5%). Approximately 38.3% adopted a single variety, 6.3% had two varieties (in various combinations of FHIA 17, FHIA 23, FHIA 25, and Yangambi KM 5), and 3.4% had other combinations (Figure 13).

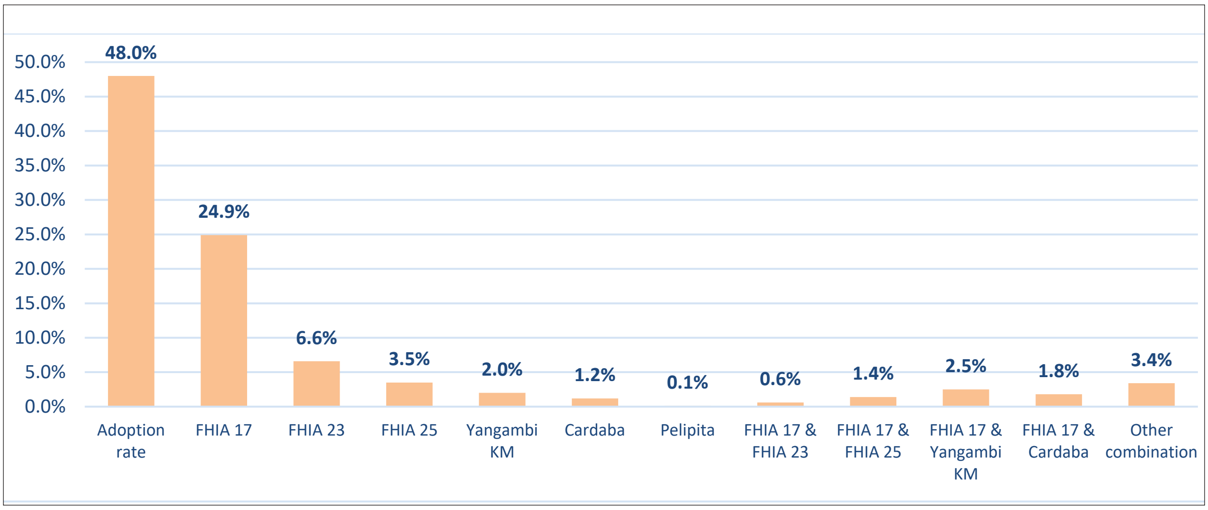

Figure 13. Adoption rate by variety.

The adoption rate varies across districts (Figure 14). Muleba district has the highest adoption rate, at 28%, followed by Ngara and Biharamulo. Muleba, Biharamulo, and Urban Bukoba have more adopters than nonadopters. The districts with the lowest adoption rates are Karagwe, Kyerwa, and Missenyi, in that order, indicating a need for increased efforts in these districts.

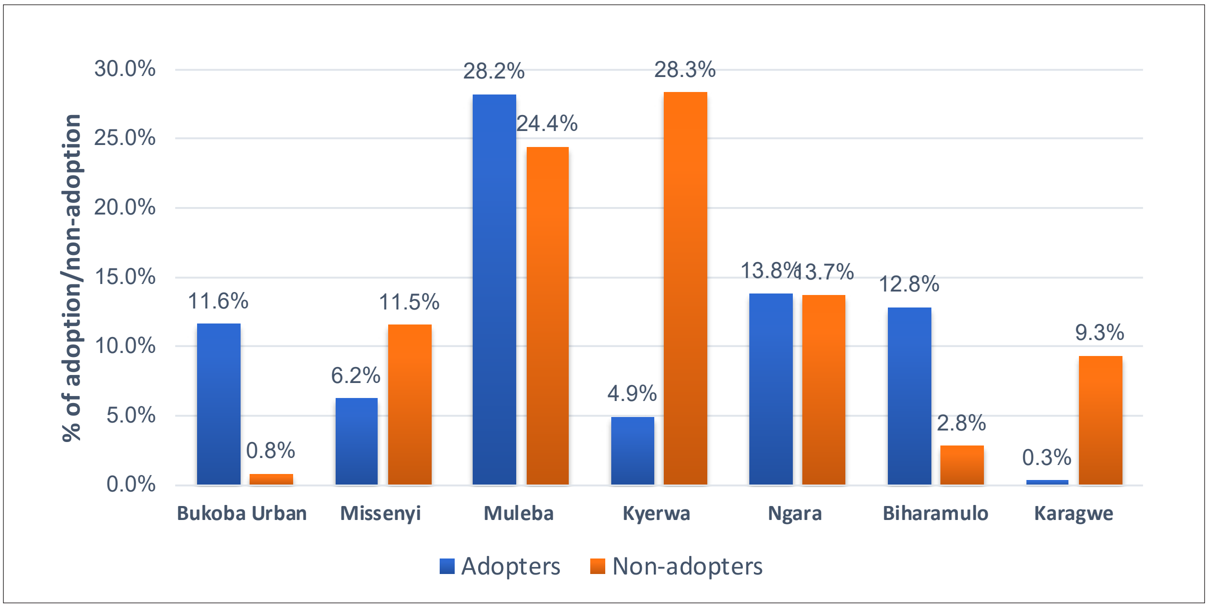

Figure 14. Adoption rate by district.

Summary statistics of independent and outcome variables by adoption status

Table 4 presents the summary statistics of the independent and outcome variables by adoption status. Results show statistically significant differences in many of the variables. Adopters have more resource endowments as measured by farm size and asset value. They also have more access to credit, training programs, and off-farm employment than nonadopters. For example, on average, adopters have larger banana farms than nonadopters. The percentage of farmers having access to off-farm employment, credit, and training is higher among adopters than nonadopters. About 12.6% of adopters work off-farm jobs compared to 8.2% of nonadopters. Similarly, 11.1% of adopters received training on bananas compared to 6.8% of nonadopters. Furthermore, the percentage of farmers with commercial objectives (i.e., growing bananas primarily for income generation) is higher among adopters than among nonadopters. Nearly 40% of adopters grow bananas mainly to generate income, compared to 11% of nonadopters.

These results suggest systematic differences between adopters and nonadopters. These results suggest that resource endowments (larger banana farms and assets), access to off-farm employment, credits, and training, as well as banana farming experience, female headship, and growing bananas for income generation, are positively associated with SBV adoption, without controlling for all other characteristics. While such descriptive results are helpful for an initial investigation of the factors influencing the probability of adoption, they do not provide a deep insight into the factors predicting adoption. Further, the summary statistics of the outcome variables (yield, per capita household income, and per capita calorie consumption), presented in Table 4, show statistically significant mean differences between adopters and nonadopters. Adopters obtained significantly higher yields, per capita household income, and per capita calorie consumption than nonadopters. However, since adopters and nonadopters may differ systematically on other factors, the mean difference between them cannot provide a causal estimate of the effects of adopting SBVs.

The following sections present the results of the multivariate analysis of adoption using the ESR model, considering three outcome variables and an interplay of multiple predictors while controlling for all other factors.

Table 4. Mean comparison of farm characteristics between adopters and nonadopters.

Farm/household characteristics	Full sample	Adopters	Nonadopters	Mean difference	SE of mean difference
Sex (1 = male)	0.923	0.899	0.946	–0.046***	0.015
Age (years)	47.064	47.809	46.374	1.435**	0.683
Age square	2359.49	2421.940	2301.694	120.246*	66.550
Education (years)	7.221	7.144	7.292	–0.148	0.155
Marital status (1 = married)	0.910	0.882	0.936	–0.054***	0.016
Household size (#)	5.897	5.977	5.823	0.154	0.127
Banana farm size (ha)	1.059	1.265	0.868	0.397***	0.048
Livestock size (TLU)	2.638	2.105	3.131	–1.026***	0.316
Own bicycles(1 = yes)	0.308	0.367	0.253	0.114***	0.026
Own motorbikes(1 = yes)	0.457	0.411	0.500	–0.089***	0.028
Access to credit (1 = yes)	0.168	0.193	0.146	0.047**	0.021
Off-farm jobs (1 = yes)	0.103	0.126	0.082	0.044**	0.017
Commercial purpose (1 = yes)	0.246	0.391	0.112	0.279***	0.023
Participation in training (1 = yes)	0.089	0.111	0.068	0.042***	0.016
Participation in agriculture training	0.127	0.117	0.137	0.019	0.019
Plot managed by a man (1 = yes)	0.215	0.218	0.213	–0.005	0.023
Plot managed by a woman (1 = yes)	0.670	0.624	0.713	–0.088***	0.027
Experience in banana cultivation (years)	17.307	17.107	17.493	–0.386	0.639
Harvestable plants (#)	255.004	242.100	266.945	–24.845	14.609
Established mats (#)	331.869	310.674	351.484	–40.811**	16.6100
Crop system (1 = intercropping)	0.944	0.955	0.935	0.020	0.013
Elevation (1 = highland)	0.162	0.091	0.228	–0.138***	0.010
Bukoba District Council	0.156	0.223	0.093	0.130***	0.020
Bukoba Urban	0.060	0.116	0.008	0.108***	0.013
Missenyi	0.089	0.062	0.115	–0.053***	0.016
Muleba	0.262	0.282	0.244	0.038	0.025
Kyerwa	0.170	0.049	0.283	–0.234***	0.020
Ngara	0.137	0.138	0.137	0.001	0.020
Biharamulo	0.076	0.128	0.028	0.100***	0.015
Karagwe	0.05	0.003	0.093	–0.090***	0.012
Yield (ton/ha)	15.945	23.106	9.317	13.789***	1.129
Per capita household income (USD at PPP)	1.173	1.837	0.558	1.280***	0.147
Per capita calorie consumption	4085.627	6394.067	1949.226	4444.841***	370.793
No. of observations	1240	596	644		

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

Multivariate estimation results

Adoption determinants

The hypothesized predictors of the model have been categorized into demographic, farm, and regional characteristics. To identify the barriers to adoption, we relied on the first-stage parameter estimates from the selection equation of the ESR model, as presented in Table 1A of the Annex. Among demographic factors, the household head's age and the sex of the banana plot manager are associated with the adoption of SBVs. The coefficient of the linear age term is positive, while that of the age-square term is negative, suggesting that the probability of adoption initially increases with age but then diminishes beyond a certain age. The probability of adopting SBVs is lower for households with female-managed plots compared to those with jointly managed plots. In other words, joint management influences the adoption of SBVs. Among socioeconomic factors, the size of banana farms is associated with the adoption of SBVs. Among farm factors, elevation has a statistically significant relationship with the adoption of these varieties. Households with access to credit are more likely to adopt SBVs because financial access enables them to purchase planting materials and associated inputs (e.g., hire labor). Finally, the results suggest differences in the likelihood of adoption between the high- and mid-altitude ecological zones, as well as among administrative districts. For example, households in the mid-altitude zone are more likely to adopt than those in the highland zone. Bukoba Urban and Biharamulo are also more likely to adopt the SBVs than the reference district (Bukoba Council). The other districts are less likely to adopt SBVs than the reference district. The multivariate results corroborate the descriptive results presented in Table 4.

ESR model diagnostics and parameter estimates of the outcome equations

We estimated the ESR model, as specified in the materials and methods section. The results of the model diagnostics for the yield outcome equations are presented in Table 1A in the Annex. When estimating an ESR model, it is often advised to include an instrument for model identification, although the model can be identified due to the nonlinearity of the selection bias control terms (Maddala, 1986). Hence, we included elevation as an instrument in the selection (or adoption) equation, as used in Edmeadeset et al. (2007). We chose elevation because it may correlate with climatic conditions, such as rainfall and temperature, that influence disease and pest pressures, as well as soil fertility conditions, which can drive farmers to seek and adopt disease- and pest-resistant crop varieties. SBVs were introduced into Kagera to address disease and pest problems. Hence, we expect elevation to influence a farmer's decision to adopt, but not to directly affect yield levels. We verified its relevance by testing its statistical significance in the selection (or adoption) equation.

The results of the LR test of independent equations [$\chi2(1) = 5.23$, $P > 0.05$] indicate that the null hypothesis of joint independence between the adoption and yield equations is rejected for both adopters and nonadopters. The correlation coefficients (denoted by) between the error terms of the SBV adoption and the yield equations for adopters and nonadopters are also statistically significant, confirming the results of the LR test. These results suggest the presence of self-selection among both adopter and nonadopter groups, which validates the appropriateness of the estimated ESR model over standard regression models. This means that the unobservable characteristics or omitted variables influencing the adoption decisions of adopters and nonadoption decisions of the nonadopters also affect their respective yield outcomes. Households with an above-average propensity to adopt SBVs tend to perform above average compared to a random household from the population. Hence, the observed difference may overstate the true effect of adoption. The results also indicate that the parameter estimates of the covariates in the outcome equations of the ESR model differ significantly between the two regimes, as shown in Table 1A. The results reveal noticeable differences in some of the parameter estimates of the yield outcome equations between adopters and nonadopters, indicating the presence of heterogeneity within the sample. For example, results reveal gender gaps in banana productivity among adopters. Adopters with women-managed plots are less productive than those with jointly managed plots. In contrast, nonadopters with women-managed plots are equally productive as those with jointly managed plots. These results suggest that a more targeted approach to increase women's access to SBVs could lead to overall increased banana production. The household head's education, years of experience in banana cultivation, and ownership of radio and television are significantly associated with yield outcomes for adopters but not for nonadopters. Conversely, intercropping, access to credit, participation in banana training, and motorcycle ownership are significantly associated with yield outcome for nonadopters but not for adopters.

The model diagnostics results of the per capita calorie consumption equations are presented in Table 2A in the Annex. As in the yield outcome equations presented in Table 1A, the LR test of independent equations [$\chi2(1) = 28.21$, $p > 0.01$] rejected the null hypothesis of joint independence between the adoption and per capita calorie consumption equations. The correlation coefficient (ρ) between the error terms of the SBV adoption and the per capita calorie consumption equations for adopters and nonadopters is also statistically significant, rejecting the null hypothesis of no selection bias. The results revealed noticeable differences in the effects of the predictors between adopters and nonadopters, validating the use of ESR over a standard regression and providing group-specific insights. For example, the household's age, education, and group membership are important predictors of the per capita calorie consumption for adopters but not for nonadopters. Conversely, marital status, participation in banana-related training, and radio ownership are important predictors for nonadopters.

The model diagnostics results of the per capita household income equations are presented in Table 3A in the Annex. As in the case with the above two models, the LR test for the independence of the selection equation and the outcome equations rejects the null hypothesis of the absence of selection bias [($\chi2(1) = 7.45$, $p > 0.01$]. However, the correlation coefficients are not statistically significant, likely due to the inadequacy of power to detect the selection bias. Based on the LR test results, which suggest that selection bias may be caused by unobservable variables, we maintain the ESR results. There are noticeable differences in the effects of the predictors, providing group-specific insights. For example, results reveal gender gaps in per capita household income. Adopters with women-managed plots earn lower incomes than those with jointly managed plots. In contrast, nonadopters with women-managed plots are equally likely to earn incomes as those with jointly managed plots. These results suggest that a more targeted approach to increasing women's access to SBVs could lead to higher income and improved household food security. Additionally, own savings and assets (such as motorbike ownership and radio ownership) are important determinants of the per capita household income for adopters but not for nonadopters. Conversely, the household head's sex, marital status, and number of established banana mats are important determinants of the per capita household income for nonadopters but not for adopters.

In summary, the model diagnostics results validate the appropriateness of the chosen empirical model (ESR) for our data and account for the selection bias resulting from the influence of unobservable characteristics. If we had not addressed it, we would have biased estimates, leading to misguided policy recommendations. The next sections present the unbiased estimates of productivity and household food security impacts on actual adopters.

Productivity impacts on the adopters

The distributions of the yield effects of SBV adoption on banana adopters under observed and counterfactual conditions are shown in Figure 15. The observed distribution curve represents the actual yields of the adopters, while the counterfactual distribution curve represents a hypothetical outcome that would have occurred if the same adopters had not adopted. The counterfactual curve serves as the baseline yield at a given probability level on the y-axis, illustrating the path that the banana farmers would have followed had the banana breeding or improvement programs not been implemented in Kagera. The y-axis represents the probability of achieving a certain yield level or lower, and the x-axis represents the yield levels. Since the counterfactual distribution curve of yield for adopters (red line) lies predominantly to the left of the observed (blue line) at a given probability level (y-axis), such as a value of 0.5 that corresponds to the median of the distribution, the adopters would have produced lower yields if they had not adopted. In other words, adoption improved banana productivity. The ESR model estimates of the average treatment effects on the treated (ATT) show that adopters achieved a 15% productivity gain (1.8 tons/ha), with yield shifting rightward from 12.2 tons/ha without adoption to 14.0 tons/ha with adoption ($p < 0.01$). This finding is consistent with Nkuba's (2007) impact studies on FHIA hybrids in Kagera.

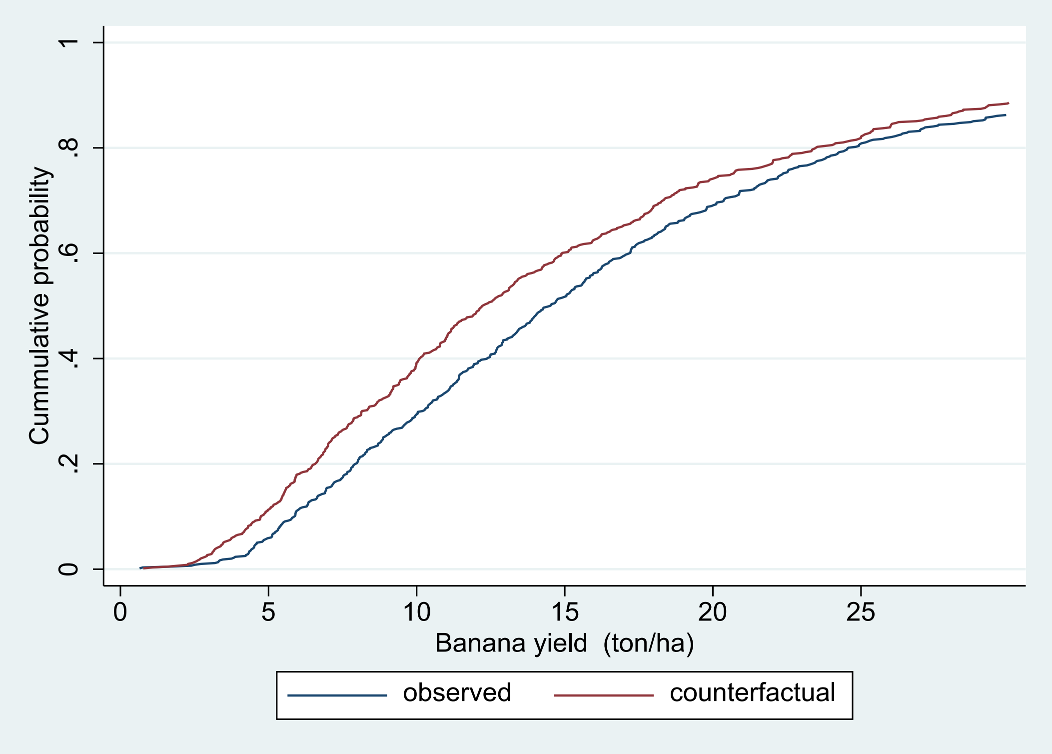

Figure 15. Observed and counterfactual distribution of banana yield.

Household food security impacts on adopters

Consistent with the yield distributions shown in Figure 15, the counterfactual distribution curve of per capita calorie consumption for adopters (red line) lies predominantly to the left of the observed (blue line) (Figure 16). This suggests that, at a given probability level, adopters would have been worse off if they had not adopted. In other words, adoption led to an improvement in per capita calorie consumption. The observed average daily per capita caloric intake for adopters was 3,165 kcal in the 2023/24 season. Had they not adopted the SBVs, they would have consumed 2,491 kcal, representing a 27% increase ($p < 0.01$) (Table 5).

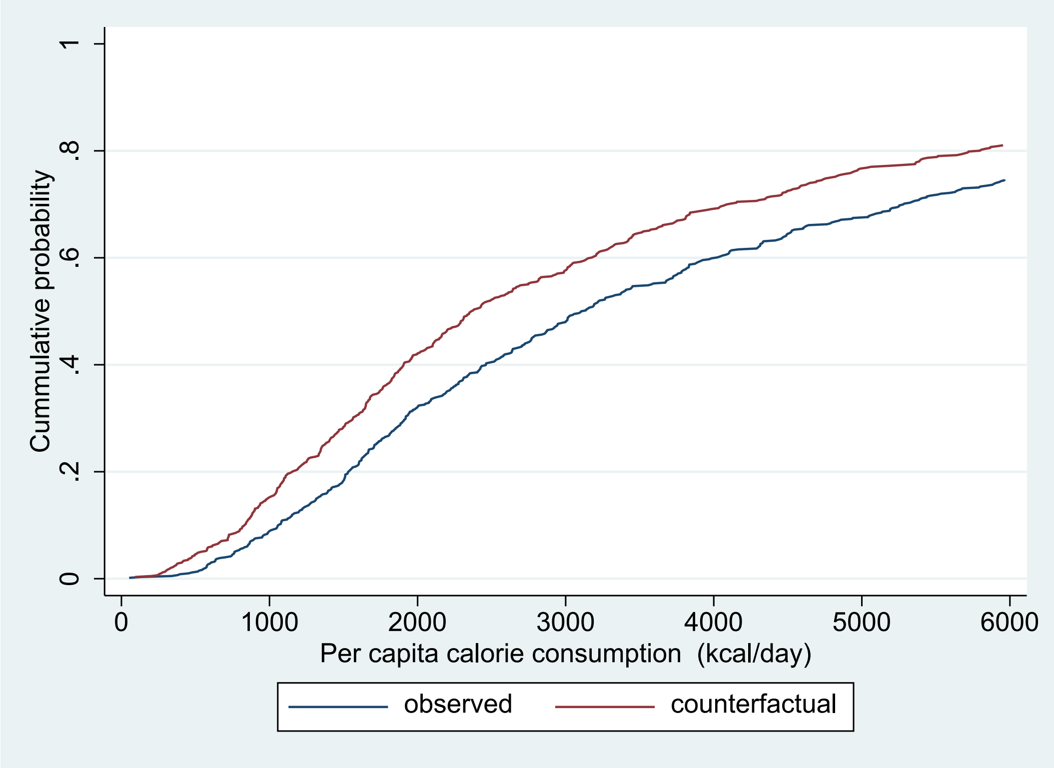

Figure 16. Observed and counterfactual distribution of per capita calorie consumption.

Using the Foster, Greer, and Thorbecke (FGT) indices, the observed household food insecurity headcount ratio among adopters, based on per capita calorie consumption in 2024, was 0.335. However, had they not adopted the SBVs, the headcount ratio would have increased to 0.433 (the counterfactual food insecurity headcount ratio), indicating a 9.8 percentage point reduction in the incidence of food insecurity among adopters (Table 5). Results based on the per capita household income indicator also showed that adoption led to an 11-percentage point reduction in the food insecurity headcount ratio.

Table 5. Impact of the adoption of SBVs on household food insecurity reduction.

Outcome	Banana household type and treatment effect	Decision stage		Treatment effects
		To adopt	Not to adopt	
Per capita calorie consumption (Kcal/p/day)	Adopters (ATT)	3,165	2,491	674***
Food insecurity headcount ratio	Adopters (ATT)	0.335	0.433	–0.098***
Food insecurity gap index	Adopters (ATT)	0.121	0.181	–0.060***
Food-insecure squared gap index	Adopters (ATT)	0.061	0.100	–0.039***
Per capita income (USD)	Adopters (ATT)	1.376	0.417	0.959***

*** $p < 0.01$

Number of food-insecure households that became food secure due to adoption

Given the 9.8 percentage point reduction in the food insecurity headcount ratio based on the per capita calorie consumption (Table 5), an estimated 20,934 households (≈ 0.098 × 213,609 adopters), equivalent to 125,602 individuals (≈ 20,934 × 6 individuals per household) have become food secure due to adopting the SBVs in the eight districts of Kagera, with Muleba accounting for the highest number of food-secure households, followed by Kyerwa and Bukoba districts (Table 6).

Similarly, given the 11-percentage point reduction in the food insecurity headcount ratio based on the per capita household income as a proxy for the access dimension of food security, an estimated 23,497 households (≈ 0.11 × 213,609 adopters), equivalent to 140,983 individuals, became food secure.

Table 6. Number of food-insecure adopters who became food secure across districts.

District	# of the food insecure who became food secure (based on the per capita consumption indicator)
Bukoba District Council	19,594
Bukoba Urban	7,536
Missenyi District Council	11,304
Muleba	32,782
Kyerwa	21,352
Ngara	17,207
Biharamulo	9,546
Karagwe	6,280
Total	**125,602**

Direct contribution of SBV adoption to Kagera’s economy

Beyond establishing the causal relationship between the adoption of SBVs and productivity gains, as well as the reduction in household food insecurity (measured by per capita calorie consumption and per capita household income), we extrapolated the direct contribution of SBV adoption to the region’s economy and food security.

Given an estimated 213,609 adopters of SBVs in the region, adopters generated approximately 927,061 tons of bananas, with an average yield of 14 tons/ha and an average banana farm size of 0.31 hectares in the 2023/2024 season. Were it not for the adoption of SBVs, the banana production would have been 807,868 tons. This indicates that SBV adoption enabled the additional production of 119,194 tons, adding approximately 7 million USD worth of bananas to the region’s economy each year, given an average price of 59 USD per ton. The added banana output accounts for 10.5% and 6.1% of Kagera’s and Tanzania’s banana production, respectively. Furthermore, considering an average bunch weight of 43 kg per plant from field measurements, the additional production due to the adoption of SBVs (119,194 tons) was delivered by an estimated 2.8 million plants in 2024, equivalent to 13 plants per household, potentially replacing the composition of the SBVs and local varieties. The SBV distribution through KCDP started with 71,000 plants in 1997.

Conclusion

The Government of Tanzania and the Belgian Technical Cooperation cofinanced two major banana improvement initiatives in Kagera in the late 1990s and 2000s to introduce, propagate, and disseminate high-quality banana varieties called “Superior Banana Varieties” (SBVs). Despite the implementation of the initiatives for nearly 25 years, there is scant information on how the SBVs impacted Kagera. In late 2024, we conducted an adoption and impact study in two phases. The first phase aimed to understand the technological, biophysical, and socioeconomic contexts of the SBV adoption in Kagera based on FGDs with farmers and KIIs with value chain actors and stakeholders. The second phase aimed to quantify the adoption rates of SBVs and their socioeconomic impacts based on household survey data.

The results from phase 1 revealed that banana diseases (Fusarium wilt, Sigatoka, Banana Xanthomonas Wilt) and pests (weevils and nematodes) remain a critical threat to banana cultivation, affecting more than half of the farmers in the region. However, the odds of an SBV adopter being vulnerable to diseases are approximately half those of a nonadopter, suggesting that the adoption of SBVs may have mitigated yield losses among adopters. Farmers cultivate endemic landraces, exotic landraces, and hybrids. They integrated SBVs with local varieties to ensure marketability and meet taste preferences, as SBVs have better market demand and prices and are perceived to be tolerant of diseases and pests, while local varieties are preferred for their social (e.g., weddings, funerals) and family needs. Farmer-to-farmer dissemination is the primary channel for information exchange and the acquisition of plant materials. Most farmers learned about SBVs and acquired banana planting materials from demonstration fields, friends, neighbors, and relatives, underscoring the role of informal social networks. Farmers’ preferred traits include tolerance to diseases and pests, minimal organic fertilizer requirements, adaptability to poor soil conditions, high yields with large fingers and bunches, better quality for juice and brewing, multipurpose use for cooking, desserts, and roasting, and strong marketability. Banana value chain actors (processors and traders) are interested in additional traits in existing SBVs (e.g., increasing sugar content for FHIA 25 and extending shelf life for Yangambi KM 5).

The results from the second phase determined the adoption rates of SBVs and identified their determinants in Kagera, Tanzania. The adoption rate of SBVs in 2024 was 48%, with 38.3% adopting one variety (mostly FHIA 17) and 9.4% having at least two varieties (a combination of FHIA 17, FHIA 23, FHIA 25, and Yangambi KM 5). The three most adopted SBVs are FHIA 17 at 25% of farmers, followed by FHIA 23 (6.6%), and FHIA 25 (3.5%). The major determinants of SBV adoption include the age of the household head, sex of the plot manager, banana plot size (measured by the number of established banana mats and plants), access to credit, and the elevation and geographical location of the residence. Only a few agronomic practices have been widely adopted to improve yields. The most widely used practices include desuckering, denuding, mattocking, intercropping, hand-weeding, mulching, and propping. Improved practices, such as treating/disinfecting sucker corms, post-harvest management, bunch thinning, and de-handling false hands, are notably absent.

SBV adopters achieved a 15% increase in productivity (1.8 tons/ha), resulting in a 119,624-ton increase in the region’s output, which contributed nearly 7 million USD yearly to the region’s economy. The added banana output accounted for 10.5% of the region’s and 6.1% of the national banana output.

The additional output resulted in a reduced headcount ratio, increased depth, and a decrease in the severity of food insecurity in Kagera. Based on the increase in the per capita calorie consumption indicator, an estimated 20,934 food-insecure adopting households (≈ 125,602 individuals) became food secure, with adopters in Muleba district accounting for the highest number of food-secure households, followed by Kywera and Bukoba districts. However, a third of the adopting households (71,559) remain food insecure despite adoption.

The impact model estimation results are consistent with stakeholders and value chain actors' qualitative assessment gathered through KIIs, validating that the SBVs reinvigorated banana dynamics through (i) increased banana production for smallholder farmers, (ii) increased versatility of banana utilization for processors due to preferred traits for beverage making (e.g., Yangambi KM 5 and FHIA 25) and snack making (e.g., FHIA 17 and FHIA 23), (iii) increased trade volume and sales for traders, and (iv) increased tax revenue for local governments.

The findings present essential evidence that justifies sustaining investments to support continued breeding and dissemination of SBVs, including the newly developed matooke banana hybrids. The results on farmers' adoption rates, productivity, and impact suggest a strong demand from farmers, which is essential for the future distribution of banana breakthrough products. However, it is essential to account for the farmers' contexts (needs, preference traits, production priorities) and address the identified production constraints and barriers to adoption, including socioeconomic (smaller farm size), institutional (access to credit), and biophysical barriers (diseases, pests, and low fertility, as well as a lack of market price information), which are a prerequisite for successful scaling.

The SBV adoption helped a significant number of food-insecure households become food-secure (20,934 banana-growing households). It is noteworthy that these adopters added these SBVs into their existing banana-based farming systems, rather than replacing their landraces with the SBVs. The current strategy of introducing new varieties alone (with farmer-to-farmer distribution) remains insufficient to turn every food-insecure adopter into a food-secure one, as 71,559 banana-growing households remain food insecure despite SBV adoption. Therefore, seed systems need to be set up that multiply SBVs from breeding programs, accompanied by training in improved agronomy and crop protection practices, integrated into the value chain, and a market access approach. Breeding should continue with the development of disease- and pest-tolerant hybrids, but also needs to consider important postharvest traits (e.g., increased sugar content and extended shelf life) of currently cultivated popular varieties, such as FHIA 25. Agronomy should promote low-input agronomic practices that minimize intensive soil fertility management, particularly organic fertilizer application, and introduce management practices, such as treating/disinfecting sucker corms, postharvest management (to increase shelf-life), bunch thinning, dehanding of false hands, and deflowering, which are currently notably absent or emerging. It is therefore essential to target nonadopters, who are primarily subsistence growers in high-altitude zones, with a focus on addressing their barriers to adoption. Therefore, to improve banana productivity and food security, development programs should have a holistic approach.

Results revealed gender gaps in the probability of adopting SBVs. Households with woman-managed plots are less likely to adopt SBVs than those with jointly managed plots. Further, there are gender gaps in banana productivity and household income among adopters. Adopters with women-managed plots are less productive and earn lower incomes than those with jointly managed plots. In contrast, adopters with men-managed plots are equally likely to be as productive and earn incomes equal to those with jointly managed plots. These results suggest that targeting women’s access to SBVs and associated inputs could lead to increased banana production, higher incomes, and improved household food security, thereby closing the gender gap.

Finally, we acknowledge the limitations of the calorie intake and income-based indicators of food security used in the study. While we captured the food availability and access dimensions of household food security using household income and calorie consumption from on-farm staple crop production as indicators of household food security, we have not accounted for factors such as food quality, dietary diversity, or resilience to shocks like price fluctuations. We suggest that future studies combine these indicators with other robust indicators to measure all four aspects of household food security, including availability, access, utilization, and stability.

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Annex

Table 1A: FIML parameter estimates of the ESR for banana yield.

Variables	Adoption	Log of yield (adopters)	Log of yield nonadopters
Sex (1 = male)	–0.049	–0.043	0.088
Age (years)	0.067**	–0.037*	0.019
Education (years)	0.001	0.034**	–0.002
Age square	–0.001**	0.000	–0.000
Marital status (1 = married)	–0.035	0.073	–0.136
Household size (#)	0.015	0.002	–0.019
Livestock size (TLU)	–0.033*	0.007	–0.001
Cropping system (1 = intercropped)	0.300	–0.247	–0.302**
Plot managed by a man (1 = yes)	–0.166	–0.292**	0.030
Plot managed by a woman (1 = yes)	–0.356**	–0.282**	0.073
Experience in banana cultivating (years)	–0.088	0.213***	0.002
Harvestable plants (#)	0.269***	0.887***	.987***
Established mats (#)	–0.038	–0.349***	–.399***
Access to off-farm (1 = yes)	0.165	0.040	0.012
Participation in banana training (1 = yes)	0.185	0.150	0.241*
Access to credit (1 = yes)	0.302***	0.128	0.186**
Own savings (1 = yes)	–0.109	–0.053	–0.085
Access to extension services (1 = yes)	–0.189	–0.139	–0.009
Participation in agri. training (1 = yes)	0.019	0.102	–0.041
Group membership (1 = yes)	–0.033	0.017	–0.083
Own mobile phone (1 = yes)	0.814*	–0.176	0.022
Own bicycles (1 = yes)	0.084	0.039	–0.032
Own motor bicycles (1 = yes)	–0.041	–0.043	–0.188***
Own radio (1 = yes)	0.083	0.148*	0.053
Own TV (1 = yes)	0.201**	–0.160**	0.090
Bukoba Urban	1.206***	0.440***	0.022
Missenyi	–0.297**	–0.165	–0.144
Muleba	–1.624***	–0.123	–0.027
Kyerwa	–0.269*	–0.483**	–0.286
Ngara	0.462**	0.013	0.020
Biharamulo	–2.377***	0.206	0.616***
Karagwe	1.206***	–0.774	–0.564**
Elevation (instrument)	–0.313***	–	–
Constant	–3.137***	6.605***	5.463***
lnσ1		–0.221***	
ρ1		0.498**	
$\ln\sigma_0$			–0.317***
ρ_0			0.662**

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

LR test of independence equations: $\chi2(1) =$ 5.23 Prob > $\chi2 = 0.022$

Table 2A: FIML parameter estimates of the ESR for per capita calorie consumption.

Variables	Log of per capita calorie consumption (adopters)	Log of per capita calorie consumption (nonadopters)
Household size (#)	–0.107***	–0.146***
Sex (1 = male)	–0.022	0.109
Age (years)	–0.067**	–0.004
Education (years)	0.037**	–0.015
Age square	0.001**	0.000
Marital status (1 = married)	–0.014	–0.340*
Livestock size (TLU)	–0.020	0.015
Cropping system (1 = intercropped)	0.104	0.085
Plot managed by a man (1 = yes)	–0.176	0.047
Plot managed by a woman (1 = yes)	–0.131	0.050
Experience in banana cultivating (years)	0.401***	0.115**
Harvestable plants (#)	0.908***	1.035***
Established mats (#)	–0.069	–0.094**
Access to off-farm (1 = yes)	0.191	0.070
Participation in banana training (1 = yes)	0.005	0.226**
Access to credit (1 = yes)	0.368***	0.224***
Own savings (1 = yes)	–0.058	–0.082
Access to extension services (1 = yes)	–0.191	–0.083
Participation in agri. training(1 = yes)	–0.085	–0.089
Group membership (1 = yes)	0.169*	–0.096
Own mobile phone (1 = yes)	0.109	0.312
Own bicycles (1 = yes)	–0.008	0.034
Own motor bicycles (1 = yes)	–0.121	–0.120**
Own radio(1 = yes)	0.131	0.118**
Own TV (1 = yes)	–0.040	0.091
Bukoba Urban	–0.336**	0.520*
Missenyi	–0.575***	–0.160
Muleba	–0.321***	–0.080
Kyerwa	–0.952***	–0.377***
Ngara	–0.464***	–0.263**
Biharamulo	–0.547***	0.195
Karagwe	–0.523	–0.419***
Constant	4.568***	3.340***
lnσ1	0.026	
ρ1	0.920***	
$\ln\sigma_0$		–0.380***
ρ_0		0.970***

* p < 0.1; ** p < 0.05; *** p < 0.01

LR test of independence equations: χ2(1) = 28.210 Prob > χ2 = 0.000

Table 3A: FIML parameter estimates of the ESR for per capita household income.

Variables	Log of per capita household income (adopters)	Log of per capita household income (nonadopters)
Household size (#)	–0.138***	–0.182***
Sex (1 = male)	0.380	0.430**
Age (years)	0.000	–0.010
Education (years)	–0.005	0.001
Age square	–0.000	0.000
Marital status (1 = married)	–0.300	–0.352*
Livestock size (TLU)	0.062***	0.036***
Cropping system (1 = intercropped)	–0.013	–0.045
Plot managed by a man (1 = yes)	–0.184	0.021
Plot managed by a woman (1 = yes)	–0.281**	–0.009
Experience in banana cultivating (years)	–0.006	–0.032
Harvestable plants (#)	0.618***	0.148***
Established mats (#)	–0.008	0.078*
Access to off-farm (1 = yes)	0.089	0.101
Participation in banana training (1 = yes)	0.120	–0.050
Access to credit (1 = yes)	–0.106	0.046
Own savings (1 = yes)	0.381***	0.022
Access to extension services (1= yes)	–0.080	0.023
Participation in agri. training(1 = yes)	0.111	0.101
Group membership (1 = yes)	–0.274***	–0.126**
Own mobile phone (1 = yes)	1.068**	0.519**
Own bicycles (1 = yes)	0.048	0.018
Own motor bicycles (1 = yes)	0.410***	–0.019
Own radio(1 = yes)	0.325***	0.029
Own TV (1 = yes)	0.258***	0.114*
Bukoba Urban	0.479***	–0.055
Missenyi	0.245	–0.213
Muleba	0.079	–0.128
Kyerwa	0.785*	–0.073
Ngara	0.565***	–0.038
Biharamulo	0.343**	–0.320*
Karagwe	–0.022	0.022
Constant	–3.873***	–1.143**
lnσ1	–0.192***	
ρ1	0.023	
$\ln\sigma_0$		–0.500***
ρ_0		–0.089

* p < 0.1; ** p< 0.05; *** p < 0.01
LR test of independent equations: χ2(1) = 7.45 Prob > χ2 = 0.001