Working Paper:

Varietal Turnover and Diversity in Banana Production Systems in Uganda

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Abstract:

This study investigates varietal turnover dynamics in Ugandan banana farming systems by assessing diversity, examining the adoption and discontinuation rates of recently introduced varieties, and exploring the factors influencing turnover at the farm level. This addresses a critical knowledge gap in understanding the long-term retention and discontinuation factors of the improved varieties. Varietal diversity and turnover were analysed for 399 farmers using the Shannon Diversity Index (H') and the Four-Square Method, along with descriptive statistics to capture farm-level and regional variations. The results demonstrated variations in regional and farm-level banana diversity. Farmers cultivate an average of nine varieties in their fields, and farm-level diversity patterns do not mirror the regional patterns. The Shannon Diversity Index (H=2.006) and Equitability Index (EH=0.450) indicated a moderate variety range, but uneven distribution, with the Eastern and Northern regions exhibiting the highest varietal diversity and evenness. FHIA 17 was the most prevalent improved variety but experienced some decline. Regional variations in varietal turnover exist, with the eastern region leading to the introduction of improved varieties and the central region exhibiting the highest discontinuation rates. The study emphasises local contexts in banana variety management and improvement strategies, highlighting the need for breeding programs that balance agronomic performance with consumer preferences to ensure the sustainable uptake of improved varieties. We recommend implementing a varietal replacement strategy with clear targets and incentives to encourage farmers to adopt improved varieties, improve varietal tracking using digital platforms and surveys to monitor progress and inform decision-making, and strengthen the seed value chain to ensure a sustainable supply of high-quality planting materials.

Keywords: Banana production systems, Varietal Turnover, Indices, genetic diversity, banana seed system

1. Introduction

Varietal turnover, the process by which farmers replace existing crop varieties with new ones, is crucial for assessing the long-term impacts and sustainability of agricultural interventions (Andrade-Piedra et al. 2022). High turnover rates may indicate varietal susceptibility to diseases, suboptimal yield performance, or misalignment with farmer preferences, whereas low turnover could suggest successful integration of new varieties (Thiele, 2021). Varietal turnover is particularly important in banana farming, in which genetic diversity plays a crucial role in addressing production challenges. Over the past 40 years, varietal improvement research has been central to enhancing crop productivity and food security (Evenson and Gollin 2003). Agricultural research institutions have improved banana varieties to address pests, diseases, and declining soil fertility. Adopting these improved varieties is essential for mitigating negative impacts on farm productivity and food security (Zhou et al., 2023). The significance of genetic diversity is particularly pronounced in countries such as Uganda, where bananas have immense cultural and economic value. Genetic diversity is crucial for addressing the various biotic and abiotic challenges faced by banana production, such as banana weevils, bunchy top viruses, droughts, and wind damage (Chabi et al., 2018). In Uganda, endemic banana varieties are currently threatened by pests and diseases, emphasising the need for conservation efforts and the introduction of resistant varieties.

Bananas are crucial to Uganda's agriculture, with 45% of farming households cultivating them, and the country with the highest global per capita consumption (220-400 kg annually) (Lee, 2023). This emphasises the need for robust seed systems to maintain varietal diversity. Understanding varietal dynamics is essential for guiding R&D initiatives. Previous studies have primarily focused on the initial adoption rates of improved banana varieties, neglecting the factors that influence long-term retention and discontinuation. Without insight into these factors, interventions may fail to address farmers' needs, potentially compromising crop resilience, livelihoods, and food security.

Research on banana varietal adoption in Uganda has revealed mixed results, with several key factors influencing smallholder farmers' choices. Hybrid banana varieties (HBVs) are valued for production attributes, while local cultivars are preferred for consumption traits. Adoption is influenced by farmers' education, household size, and interactions with banana actors. Informal seed systems and inconsistent naming pose challenges for the adoption of modern varieties (Sanya et al., 2020; Thiele et al., 2020). Historical shifts in production and the inverted-U relationship between adoption and farming experience further complicate this issue (Ainembabazi & Mugisha, 2014; Gold et al., 1999). While studies emphasise gradual technology development and continuous farmer training, there is a critical gap in understanding long-term variety retention and the factors driving discontinuation. This lack of knowledge hinders the development of effective interventions to support varietal diversity and resilience in banana production systems in Uganda. Understanding why farmers discontinue certain varieties is crucial for aligning breeding programs and seed systems with their needs and preferences.

A critical gap exists in the understanding of the long-term retention and discontinuation factors of banana varieties in smallholder farming systems. The challenges posed by informal seed systems and inconsistent naming practices complicate the adoption landscape. Breeding programs often fail to prioritize consumer-preferred traits, limiting sustained adoption (Thiele et al., 2020). This study aimed to address this knowledge gap by investigating the dynamics of varietal turnover in Ugandan banana farming systems. The research objectives were as follows.

1. To assess varietal diversity and distribution at national and regional levels using the Shannon Diversity Index.

2. To examine the adoption and discontinuation patterns of improved banana varieties.

3. To investigate socioeconomic and agronomic factors influencing varietal turnover at the farm level.

This study provides valuable insights into the varietal dynamics within Uganda's banana seed system, supporting efforts to enhance sustainability and impact. Addressing these gaps is essential for improving the resilience and sustainability of banana production systems in Uganda, thereby supporting the livelihoods of farming households.

2. Materials and Methods

2.1. Study Design and Approach

This study employed a cross-sectional survey design to measure turnover at both farm and banana variety levels across six regions (*Table 1*) and 38 districts in Uganda. The selected regions, historically significant for banana cultivation, encompass diverse agro-ecological zones and socioeconomic conditions. These districts represent a mix of traditional banana-growing areas and active community seeding systems. Data were collected from 399 smallholder banana farmers, averaging ten farmers per district. This study investigated banana varietal adoption, maintenance, and discontinuation at the farm level, focusing on currently grown, recently introduced, discontinued, or intended-to-be-dropped varieties and the factors driving these decisions. This methodology allowed for comparisons across households, districts, and regions, capturing baseline data on turnover metrics in diverse farming contexts. The study reached saturation when responses became repetitive, indicating an adequate representation of smallholder banana farmers' perspectives, challenges, and practices in the dataset.

Table 1: Regions where the study was conducted and their characteristics

Region	*No. of Districts*	*District Names*	*Banana Production Characteristics*
Central	12	Butambala, Kyotera, Luweero, Lwengo, Masaka, Mityana, Mpigi, Mukono, Nakaseke, Rakai, Ssembabule, Wakiso	Traditional banana-growing area; bananas intercropped with other crops
Western and Southwestern	9	Ibanda, Isingiro, Kiruhura, Mbarara, Ntungamo, Rwampara, Sheema, Kagadi, Kyenjojo	Commercial large-scale banana production, predominantly monocropping
Eastern	10	Bugiri, Bugweri, Iganga, Kamuli, Kapchorwa, Kumi, Manafwa, Mbale, Namisindwa, Sironko	Smaller-scale banana production; bananas intercropped with other crops
Northern and West Nile	7	Gulu, Lira, Nwoya, Oyam, Arua, Nebbi, Zombo	Emerging banana production areas with community seed multipliers in operation

2.2 Sample determination

To determine our sample size, we used data from the Uganda Bureau of Statistics (UBOS, 2019), which indicates that 47% of Uganda's 10.8 million households grow bananas. This resulted in a study population of 5,076,000 banana-growing households. We used the Taro Yamane (1964) formula, suitable for known populations, to calculate a statistically valid and reliable sample size.

$$n = \frac{N}{1 + N \cdot e^2}$$

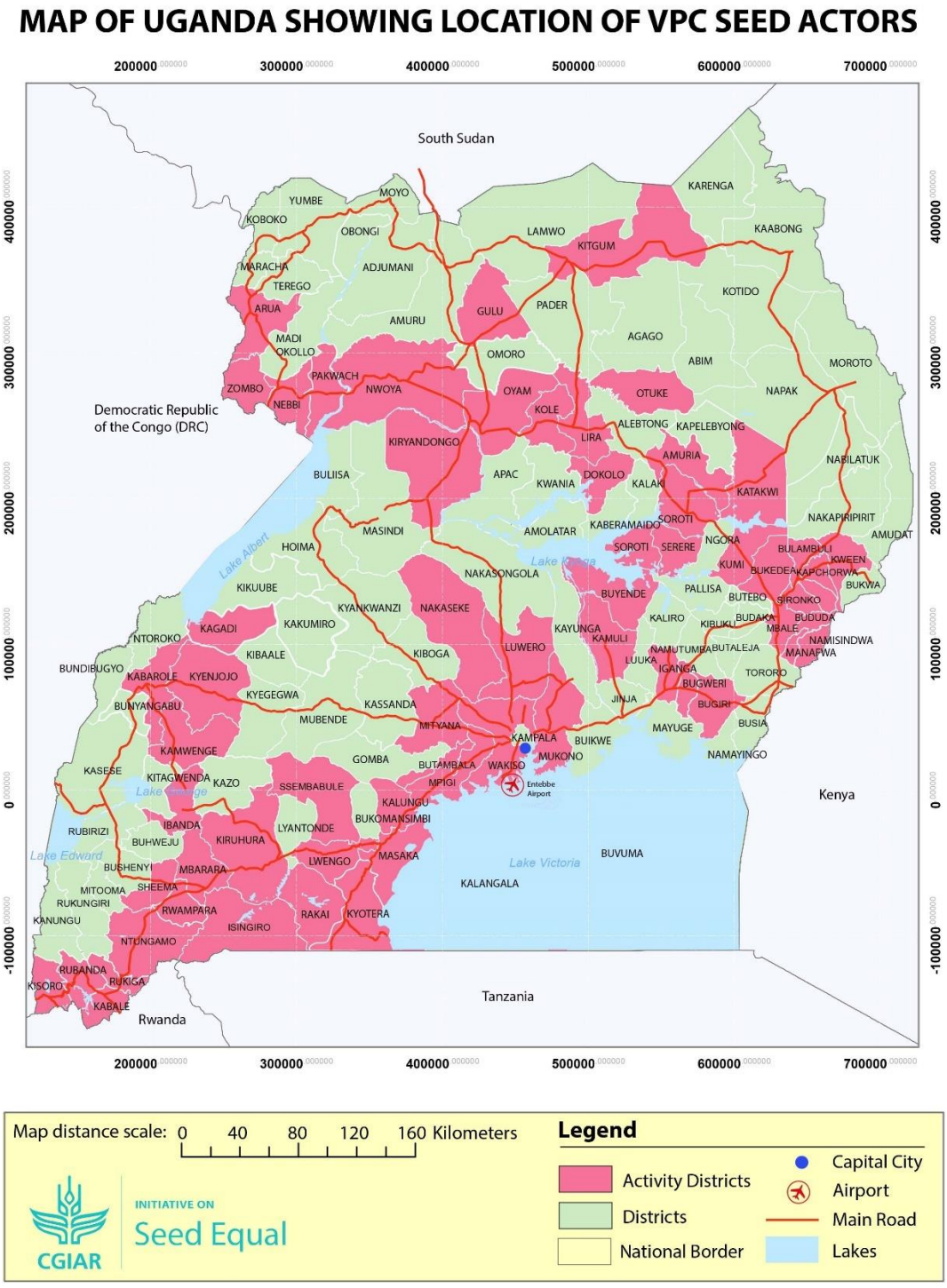
Where:

N: the total population of the study area (5,076,000 households)

e: is the level of significance (limit of tolerable error: 0.05)

n: The sample size, which in this case is 385 households, with one household member interviewed per household.

Figure 1: Map of Uganda showing the study districts, 2024, published by Mood Technologies limited



2.3 Population and Sample Selection

This study employed a multistage sampling approach to select banana fields. Initially, 38 banana-producing districts were identified for their broad geographical representation. Within each district, the sub-county with the highest banana density was chosen, followed by the parish with the highest production. From each parish, two villages were randomly selected, 10 banana fields of at least one acre were randomly chosen for the study, and the farmers who managed the selected fields were interviewed. District agricultural officers and extension workers assisted in the selection process by leveraging their local expertise.

2.4 Data collection:

The structured questionnaires were automated and uploaded to ODK software for household interviews. They were designed using the Open Data Kit (ODK) platform via ODK Build, and deployed to research assistants who conducted interviews using ODK Collect. The data were securely stored on the ODK Aggregate.

2.5 Data analysis

Data from ODK were downloaded into SPSS, STATA, and Excel for cleaning, exploration, and analysis. Descriptive statistics were used to examine the demographic data and develop turnover ratios and indices for each farmer, focusing on varieties grown, discontinued, and intended for discontinuation. To evaluate the performance of the newly introduced varieties, the number of mats served as a proxy for the cultivation area. The turnover level for each variety was calculated based on the number of farmers who grew the variety.

Table 2: Variables used in data analysis

Variables	*Type of Variable*	*Description*
Age, level of education, and farming experience	Continuous	Number of years
sex of the household head	Nominal	Male or female
Varieties currently grown	Nominal	Varieties and number of mats in the field on the day of data collection,
Varieties Recently Introduced	Nominal	Varieties introduced into the farming system within the past five years
Discontinued Varieties	Nominal	Varieties farmer stopped growing in last 5 years
Intention to Discontinue growing	Nominal	Varieties of farmer plans to drop
Reasons for introducing/discontinuing	Nominal	Farmers' reasons for introducing new varieties in the system or discontinuing production of varieties currently grown.

2.5.1. Varietal Diversity at the National and Regional Levels

To assess varietal diversity at the national and regional levels, we employed the Shannon Diversity Index (H'). This widely used ecological metric quantifies diversity by considering both richness (number of different species) and evenness (relative abundance of each species) (Spellerberg and Fedor 2003). In our context, 'species' refers to cultivated banana varieties. The **Shannon Diversity Index** is calculated as follows:

$$H' = -\sum_{i=1}^{S} p_i \times \ln(p_i)$$

where:

S: Total number of banana varieties

Pi= Proportion of the total number of mats represented by the *ith* variety

Ortiz-Burgos (2016) notes that H' values in ecological studies typically range from 1.5 to 3.5, rarely exceeding 4.0. Higher H' values (>2) indicate greater varietal diversity, suggesting a more even distribution and a higher number of banana varieties. Conversely, lower H' values reflect reduced diversity, implying dominance by one or a few varieties.

Additionally, the **Shannon Equitability Index (EH)** was used to assess species evenness, offering further insight into variety structure. The EH was calculated using the following formula:

$$E_H = \frac{H'}{\ln(S)}$$

EH values ranged from 0 to 1, with values closer to 1 indicating a more even distribution of species. Regions were compared using this index.

2.5.2. Turnover of Newly Introduced Varieties

The Four-Square Method guided the analysis of turnover of newly introduced banana varieties. This participatory tool assesses varietal diversity and adoption by categorising varieties based on popularity and cultivation area into four quadrants: 1) many farmers in large areas; 2) many farmers in small areas; 3) few farmers in large areas; and 4) few farmers in small areas. This approach provides insights into the adoption dynamics and potential turnover of each variety, revealing which are widely adopted and extensively cultivated (Mulugo et al., 2021). The analysis focused on 12 introduced varieties (figure 2) and was complemented with a comparative assessment of the drop rate (frequency at which farmers stopped cultivating a particular variety) and intention to drop (farmers' plans to discontinue a variety). These measures served as proxies for the turnover status of each newly introduced variety, aiming to identify the patterns and underlying factors contributing to variety discontinuation.

2.5.3. Variety Turnover at farm level and regional variations

To understand variety turnover at the farm level, this study drew inspiration from research examining the gains and losses in cultivated varieties over time. Penet et al. (2016) compared past and current yam varieties, introducing concepts like long-term varietal diversity dynamics. The ACCELERATE project in Tanzania focused on increasing the adoption rate of new crop varieties while phasing out older varieties (Ochieng et al., 2023). Bukero (2023) calculated an index for the weighted average age of maize varieties grown by farmers to assess varietal turnover in Ethiopia. Building on these approaches, this study considered 13 indices and ratios categorised into diversity, stability, and adoption measures.

Table 3: Indices Explanation and Interpretation

Category	***Index/Ratio Name***	***Interpretation***
Diversity	Net Varietal Change	Measures expansion or contraction in varietal diversity. Positive values show more introductions, while negative values indicate contraction.
	Introduction-to-Drop Ratio	Compares introduced to dropped varieties. A high ratio reflects active adoption with minimal rejection.
	Cumulative Turnover Rate	Tracks cumulative varietal changes over time. Higher rates indicate frequent turnover.
	Turnover Index	Combines introductions and drops relative to total varieties. Higher values indicate dynamic changes.
	Dynamic Turnover Ratio	Captures adoption, discontinuation, and drop intentions. Higher values show a more dynamic system.
Stability	Net Retention Rate	Proportion of retained varieties after subtracting drops. Higher rates suggest stability.
	Adjusted Retention Rate	Retention as a percentage of total grown and dropped varieties. Higher rates indicate effective retention.
	Stability Index	Proportion of varieties not at risk of being dropped. Higher values show greater stability.
	Variety Drop Risk Index	Proportion of varieties intended to be dropped. Higher values reflect greater risk.
	Volatility Index	Combines introductions, drops, and drop intentions to measure instability. Higher values indicate greater dynamism.
Adoption	Introduction Risk Ratio	Risk of newly introduced varieties being dropped. Higher values indicate unsustainable introductions.
	Replacement Ratio	Proportion of currently grown varieties that were introduced recently. Higher values suggest faster replacement of older varieties.
	Stopped-to-Grown Ratio	Compares stopped varieties to those currently grown. Higher values indicate frequent discontinuation relative to the current portfolio.

3. Results

3.1. Regional and Farm-Level Variability in Banana Diversity

The study revealed varying levels of banana diversity across regions (Table 4). The eastern region exhibited the highest diversity, closely followed by the southwestern region, whereas the western Nile and western regions showed the lowest diversity. The central region had a high total variety count, but fewer unique varieties, indicating an overlap with other regions. The northern region displayed moderate diversity and regional exclusivity. *A complete list of various names is provided in Appendix 1.*

At the farm level, varietal diversity was relatively high, with farmers growing an average of nine varieties across all the regions. The Southwestern and Western regions exhibited the highest farm-level diversity, whereas the northern and western Nile regions had fewer varieties. Interestingly, farm-level diversity patterns did not always mirror regional patterns, highlighting the complexity of the varietal distribution. For instance, the western region demonstrated high farm-level diversity despite lower regional diversity, suggesting concentrated pockets of varietal richness. In contrast, the northern and western Nile regions showed consistently lower varietal counts at both regional and farm levels.

Table 4: Regional-level Banana Varietal diversity

Region	No. of Varieties	Unique Varieties	Avg. No. of Varieties in Farmers' Fields	Unique Variety Names
Central	62	10	9	Bitambi, Entazinduka, Kibalawo, Muziranyama, Nakawere, Nakijumbi, Nalugolima, Namulondo, Namulonge, Salalugazi
Eastern	70	18	9	Bikowekowe, EmbiddeNamadhi, Lufuta, Makofu, Nakaki, Nakinyika, Nalugiri, Namabunga, Nambogo, Naminwe, Nandigobe, Nangeshet, Sagasaga, Embidde namonye, Kalyankoko, Nakigokye, Nasaala
Northern	41	4	9	Cavendish, Nakyetengu, Ndilanyama
Southwestern	68	17	11	Bukumu, Embidde Endilira, Embidde Engumba, Embidde Ensunyuka, Embidde Nalukira/Enyarukyira, Embidde Oruhuna, Embidde Rulimbi, Ensambasembe, Entukura, Enyashenyi/Enshenyi, FHIA 23, Mpologoma White, Mukaziaranda, Mukubakonde, NAROBAN 2 (M20), NAROBAN (M25), Nasuna
West Nile	30	1	8	Nakitambara
Western	38	1	10	Ebbani

3.2 Regional Disparities in Banana Diversity and Distribution

The Shannon Diversity Index (H=2.006) and Shannon Equitability Index (EH=0.450) provided valuable insights into the distribution and prevalence of banana varieties in the country. There is a clear regional disparity in the diversity and distribution of banana cultivation. At the country level, a moderate H value suggests a reasonable range for banana varieties. In contrast, the EH value indicates that some varieties are more dominant than others, implying an uneven distribution, with a few varieties being more prevalent. At the regional level, the Eastern and Northern regions exhibited the highest diversity (H=3.000) and substantial evenness (EH=0.752 and 0.819, respectively), suggesting that these regions have a wide range of banana varieties that are relatively evenly distributed, pointing to a more balanced banana landscape. Conversely, the Central region showed the lowest diversity (H=0.947) and evenness (EH=0.232), indicating that banana cultivation is dominated by a small number of varieties. Other regions, such as the West Nile (H=2.100, EH=0.606) and Western (H=2.000, EH=0.558), demonstrated moderate diversity and evenness, pointing to a more balanced, yet slightly uneven, distribution of banana varieties compared to the central region.

Table 5: Diversity Index () and Shannon Equitability Index

	National	Central	Eastern	Northern	Southwestern	West Nile	Western
H	2.006	0.947	3.000	3.000	2.000	2.100	2.000
HE	0.450	0.232	0.752	0.819	0.493	0.606	0.558

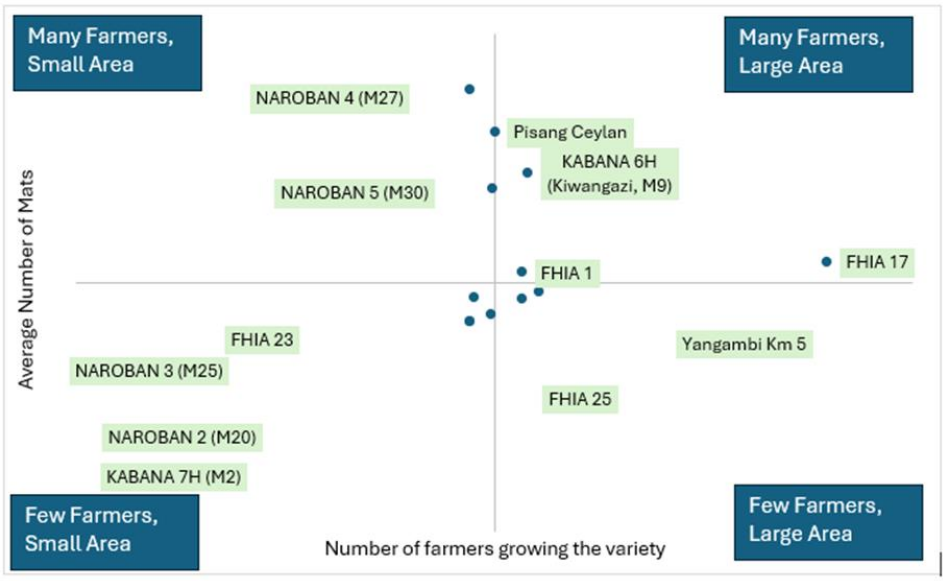
3.3. Varietal Turnover and Adoption Patterns of Improved Banana Varieties

To examine varietal turnover, the study considered a list of 12 improved varieties introduced, evaluated, and released into the banana farming system since 1990 (Figure 2). The analysis focused on examining the turnover of these varieties using descriptive analysis and the Four-Square Method to categorise varieties based on popularity and scale. The results (Figure 3) reveal adoption patterns, with some varieties exhibiting stronger widespread appeal among farmers compared to others. The FHIA 17 variety was the most popular, growing in 172 (43%) of the fields surveyed, with an average of 21 mats. Varieties such as NAROBAN 4 (M27) and Pisang Ceylan are grown by relatively few farmers but on a large scale, with an average of 77 and 63 mats per field, respectively. The KABANA 6 (M9) variety was grown by approximately 7% of the farmers surveyed, while NAROBAN 5 (M30) grew by only 3%. However, the average number of mats for these varieties was relatively high at approximately 50 mats for KABANA 6 (M9) and 45 mats for NAROBAN 5 (M30). The least-grown varieties were NAROBAN 2 (M20) and NAROBAN 3 (M25), each grown by only one farmer, with an average of approximately 2 mats.

Figure 2: List of improved varieties introduced in the farming systems in the 1990s

1. Yangambi KM 5
2. KABANA 6H (Kiwanganzi M9)
3. FHIA 1
4. FHIA 25
5. NAROBAN 4 (M27)
6. Pisang Ceylan
7. NAROBAN 5 (M30)
8. KABANA 7H (M2)
9. FHIA 23
10. NAROBAN 2(M20)
11. NAROBAN 3(M25)
12. FHIA 17

Figure 3: Popularity and scale of improved varieties



3.4 Turnover Trends in Improved Varieties: Introduction and Discontinuation Patterns

The analysis of recent turnover behaviour revealed distinct trends in the introduction and discontinuation of variety (Table 6). FHIA 17 has been introduced by 15% of farmers in the last five years, but faces some decline, with 4% discontinuing and 6% intending to drop it soon. Yangambi Km 5 shows higher turnover, with 30% adoption in the past five years, 9% discontinuation, and 17.6% planning to stop cultivation shortly. Several varieties, including FHIA 1, 25, NAROBAN 4 (M27), Pisang Ceylan, and NAROBAN 5 (M30), exhibit high discontinuation rates. These were initially adopted by a few farmers, but most had already ceased cultivation. In contrast, FHIA 23, NAROBAN 2 (M20), and NAROBAN 3 (M25) maintained a steady presence with no reported intentions of discontinuation, suggesting that they are well suited to the local farming environment.

Table 6: Varietal Adoption and Dropout Trends

Variety	*% of Farmers Growing*	*% Introduced in Last 5 Years*	*% Dropped in Last 5 Years*	*% Intending to Drop*
FHIA 17	43	15	4	6
Yangambi Km 5	9	3	1	2
KABANA 6H (M9)	7	2	0	2
FHIA 1	7	4	0	2
FHIA 25	7	2	1	1
NAROBAN 4 (M27)	3	3	0	0
Pisang Ceylan	3	1	0	0
NAROBAN 5 (M30)	3	2	0	0

KABANA 7H (M2)	1	0	0	0
FHIA 23	0.25	0	0	0
NAROBAN 2 (M20)	0.25	0	0	0
NAROBAN 3 (M25)	0.25	0	0	0

3.5. Introduction and Discontinuation Trends of Improved Varieties Across Regions

This section analyses the adoption and discontinuation patterns of improved varieties across different regions. The results highlight regional variations, with the eastern region leading to the introduction of new varieties, with 74 of the surveyed farmers growing an average of three improved varieties. In contrast, the Southwestern and Western regions recorded no new introductions in the last five years. The Central region saw the highest number of farmers discontinuing and planning to drop the growth of improved varieties, while southwestern farmers had the second-highest intention to stop growing these varieties. On average, farmers across regions cultivated nine improved varieties, with at least two new varieties recently introduced, and one discontinued or planned for discontinuation.

Table 7: Farm-level Varietal Introduction, Discontinuation, and Intentions to Discontinue

Region	*Introduced Varieties*	*Stopped Varieties*	*Intended to Drop Varieties*	*Avg. Varieties Grown*	*Avg. Introduced Varieties*	*Avg. Stopped Varieties*	*Avg. Intend to Drop*
Central	11	66	58	8.8	0.4	1.0	0.7
Eastern	74	47	39	9.2	2.9	0.9	0.6
Northern	33	11	16	8.5	4.0	0.4	0.5
Southwestern	0	38	44	11.0	0.0	1.1	1.2
West Nile	21	10	10	8.3	2.5	0.4	0.4
Western	0	12	11	10.0	0.0	1.3	1.0
Total/Average	139	184	178	9.3	1.6	0.9	0.7

3.6 Indices for Assessing Varietal Turnover: Diversity, Stability, and Adoption

To assess varietal turnover at the farm level, aggregate indices were calculated to analyse their behaviour at the national level. The criterion for inclusion was based on standard deviation, with stronger indices exhibiting smaller deviations. The analysis identifies key indicators across three categories: diversity, stability, and adoption.

Diversity: Three indices were retained because of their low variability:

- The net varietal changes (Std. Dev. = 3.0): Capture changes in varietal composition over time.

- The introduction-to-drop ratios (Std. Dev. = 1.49): This reflects the balance between newly introduced and dropped varieties.
- The cumulative turnover rates (Std. Dev. = 0.40) measured the overall varietal turnover rate.

Other diversity indices, such as the Turnover Index and Dynamic Turnover Ratio, were excluded because of their higher variability.

Stability: The two indices were retained.

- The net retention rates (Std. Dev. = 0.22) measure the persistence of varieties within the farming system.
- The volatility indices (Std. Dev. = 0.34): Capture fluctuations in varietal adoption.

Indices, such as the Adjusted Retention Rate, Stability Index, and Variety Drop Risk Index, were excluded because of their higher standard deviations, indicating lower reliability.

Adoption: Only the Introduction Risk Ratio (Std. Dev. = 0.52) was retained as it reliably captured the risk associated with introducing new varieties. Indices such as replacement ratio and stopped-to-growth ratio were excluded because of their higher variability.

The retained indices—Net Varietal Change, Introduction-to-Drop Ratio, Cumulative Turnover Rate, Net Retention Rate, Volatility Index, and Introduction Risk Ratio— provide a robust framework for analysing varietal turnover, supporting evidence-based recommendations for enhancing varietal diversity, stability, and adoption.

Table 8: Turnover level at the farm level

		N	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Diversity	Net Varietal Change	399	-8.0	19.0	0.536	3.0
	Introduction-to-Drop Ratio	184	0.00	8.00	0.68	1.49
	Cumulative Turnover Rate	399	0.00	2.00	0.33	0.40
	Turnover Index	399	-200.00	100.00	7.48	43.10
	Dynamic Turnover Ratio	399	0.00	200.00	40.21	40.61
Stability	Net Retention Rate	399	-1.00	1.00	0.87	0.22
	Adjusted Retention Rate	399	33.33	100.00	91.18	12.38
	Stability Index	399	0.00	100.00	92.32	11.45
	Variety Drop Risk Index	399	0.00	100.00	7.68	11.45
	Volatility Index	399	0.00	1.33	0.35	0.34
Adoption	Replacement Ratio	399	0.00	100.00	20.00	35.04
	Introduction Risk Ratio	139	0.00	3.00	0.27	0.52
	Stopped-to-Grown Ratio	399	0.00	200.00	12.52	22.16

3.7 Regional Variations in Varietal Turnover

Results of the diversity indicators, such as Net Varietal Change (mean = 0.536) and Cumulative Turnover Rate (mean = 0.33), showed limited but stable varietal shifts, indicating gradual transitions. The stability indices, particularly the high Net Retention Rate (mean = 0.87) and low Volatility Index (mean = 0.35), demonstrate that farmers generally retain adopted varieties. The low introduction risk ratio (0.27) suggests that caution should be exercised when introducing new varieties of rice.

Regional analysis revealed two distinct groups based on the varietal turnover patterns.

- The central and southwestern regions had lower diversity indices (Net Varietal Change: -0.68 and -1.14; Introduction-to-Drop Ratio: 0.21 and 0.00), indicating slower varietal adoption dynamics and greater varietal stability in these regions.

- The eastern, Northern, and Western Nile regions had higher diversity indices (Net Varietal Change: 2.02, 3.61, and 2.07; Introduction-to-Drop Ratio: 1.21, 2.64, and 2.40), suggesting more active varietal transitions in these regions.

Table 9: Regional differences in the turnover indices

	Region	Central	Eastern	Northern	Southwest	West Nile	Western
Diversity	Net varietal change	-.68	2.02	3.61	-1.14	2.07	-1.29
	Introduction-to-Drop Ratio	.21	1.21	2.64	.00	2.40	.00
	Cumulative Turnover Rate	.20	.52	.61	.13	.42	.14
	Turnover Index	-11.18	26.29	53.03	-13.37	30.52	-14.27
	Dynamic Turnover Ratio	27.44	58.92	67.24	24.43	46.37	23.25
Stability	Net Retention Rate	.85	.87	.96	.87	.94	.86
	Adjusted Retention Rate	89.83	91.07	96.57	89.81	95.15	89.05
	Stability Index	92.37	93.25	93.94	88.94	95.63	91.03
	Variety Drop Risk Index	7.63	6.75	6.06	11.06	4.37	8.97
	Volatility Index	.21	.51	.65	.20	.43	.19
Adoption	Replacement Ratio	.24	.32	.15		.29	
	Introduction Risk Ratio	4.31	39.23	57.10	.00	36.26	.00
	Stopped-to-Grown Ratio	15.50	12.94	4.07	13.37	5.74	14.27

3.8 Drivers of varietal turn over

Adoption is driven primarily by high market demand, pest and disease resistance, early maturity, high yield, good taste, and adaptability to local conditions. Varieties are discontinued owing to low market demand, susceptibility to pests and diseases, low yield, poor taste, late maturity, and difficulties in obtaining clean planting materials. Intentions to discontinue are influenced by similar factors, with additional concerns about perishability, poor processing quality, and the inability to

adapt to changing environments. These trends highlight the interplay between agronomic, market, and environmental factors that influence farmers' varietal turnover decisions.

DISCUSSION

1. *Varietal Diversity at the National and Regional Levels*

The banana cultivation landscape in Uganda exhibits moderate varietal diversity at the national level with notable regional variations. This uneven distribution is particularly evident when examining the regional patterns. A limited number of predominant varieties contribute to uneven distribution across the country. Understanding these factors is crucial to understanding the dynamics of banana cultivation in the country. This varietal distribution pattern is influenced by several factors including cultural requirements and market demand. Ugandan banana farmers typically cultivate approximately 10 distinct cultivars to ensure continuous harvest and address various consumption and cultural requirements (Kilwinger et al., 2019). The perennial nature of bananas restricts opportunities for introducing new varieties because planting primarily occurs through gap-filling processes. This limited opportunity for varietal introduction highlights the importance of the existing diversity and farmer decision-making processes. Market demand also influences varietal adoption, in conjunction with farmer preferences. As noted by Thiele et al. (2021), despite resisting leaf spot and increased yields, improved banana varieties often lack the specific organoleptic qualities demanded by consumers, which limits their adoption.

This regional variation in diversity indices provides insights into the complex factors that shape banana cultivation practices across Uganda. The Eastern and Northern regions of Uganda demonstrated higher banana diversity indices, reflecting localised agroecological and cultural practices (Kilwinger et al., 2019). The dominance of a few key varieties in the central region mirrors the trends observed in other crop systems, such as yams (Penet et al., 2016). The variation in banana diversity across regions indicates the complex interplay between agronomic benefits and consumer preferences. These regional differences underscore the importance of considering the local context when developing strategies for banana variety management and improvement. The implications of these findings extend beyond the banana cultivation system as the observed patterns are not unique to this crop.

2. *Turnover of Improved Varieties: Adoption and Discontinuation patterns*

This study elucidates the diverse adoption patterns and scales of improved banana varieties, reflecting their varying levels of prevalence and utility among farmers. These adoption patterns are influenced by multiple factors, including farmers' preferences and risk management strategies. For instance, FHIA 17 demonstrated widespread adoption and was cultivated by numerous farmers on a moderate scale. Kilwinger et al. (2019) posit that farmers adopt newly introduced, higher-yielding cultivars, in a trial-based manner by integrating them into their existing portfolio of cultivars rather than fully replacing their local varieties. This adoption strategy reflects a balance between

innovation and traditions in agricultural practices. This cautious approach reflects farmers' concerns regarding the potential loss of local varieties with superior traits such as palatability or significant cultural value, as evidenced by the widespread adoption of improved cultivars, albeit on a small scale. The adoption patterns of different banana varieties revealed a complex interplay between farmers' needs, preferences, and local conditions.

The adoption of certain improved varieties by a limited number of farmers, but on a large scale, suggests niche utilisation. The presence of niche varieties highlights the diversity in farmers' needs and the significance of variety-specific traits. This aligns with the findings of Kilwinger et al. (2020), who observed that certain banana varieties are adopted for their unique attributes but often remain confined to specific farmer segments. This observation underscores the importance of considering both varietal characteristics and external factors to understand adoption patterns. As shown in this study, some improved varieties achieve widespread adoption, whereas others face challenges in gaining traction among farmers.

Generally, farmers' decisions to adopt or discontinue banana varieties reflect broader trends in the VPC systems. Varieties with favourable agronomic traits, such as high yield, pest resistance, and market appeal, have been widely adopted, as observed in cassava studies in East Africa (Andrade-Piedra et al., 2022). However, susceptibility to pests, poor taste, and low yields have driven the discontinuation and paralleling patterns observed in yams and sweet potatoes (Penet et al., 2016). Our findings align with Thiele et al. (2021), who observed the necessity for breeding programs that prioritise both agronomic and consumer-preferred traits to ensure the sustainable uptake of improved varieties.

3. Varietal Turnover Levels at the Farm Level

At the national level, Uganda's banana farming system is characterised by gradual changes in diversity, strong varietal stability, and cautious adoption of improved varieties. Understanding the varietal dynamics that drive these trends is crucial for interpreting broader patterns. Kilwinger et al. (2019) highlights that traditional, low-yielding varieties are often retained due to superior organoleptic qualities and cultural significance, contributing to their stability in farming systems. While national trends provide a broad overview, a closer examination of regional dynamics reveals a more detailed picture of banana varietal adoption in Uganda. The Central, Western, and Southwestern regions exhibited slower adoption and greater stability, suggesting potential resistance to new varieties, possibly due to the importance of tradition and culture. In contrast, the Eastern, Northern, and Western Nile regions display more dynamic adoption behaviour, with higher diversity indices and more frequent transitions between varieties. These regional disparities in varietal adoption and retention raise important questions regarding the underlying factors driving such diverse patterns across Uganda's banana farming landscape.

The reasons for these regional variations are multifaceted, encompassing environmental, economic, and cultural factors. Thiele et al. (2021) posited that regions with diverse agroecological conditions

and robust market linkages exhibit a higher propensity for experimentation with new varieties. In such areas, farmers are more inclined to adopt cultivars with enhanced agronomic performance, often driven by the necessity to adapt to challenging conditions or to meet market demands. This trend is corroborated by Sanya et al. (2020), who observed that farmers in Eastern Uganda demonstrated a greater willingness to adopt hybrid varieties, such as FHIA hybrids, due to their favourable market traits and adaptability. However, it is imperative to note that higher turnover rates in these regions do not invariably indicate long-term adoption success. Turnover indices may reflect ongoing experimentation because farmers evaluate new varieties under diverse conditions to ascertain their viability.

Beyond these regional differences in adoption rates and strategies, it is crucial to consider the structural elements that shape varietal dynamics at a fundamental level. The interplay between structural influences and regional variation in adoption patterns contributes to the complex tapestry of banana varietal dynamics in Uganda. According to Mulugo et al. (2023), accessibility to clean planting materials and the support provided by community seed systems significantly influence adoption rates. These factors may explain the higher turnover rates observed in certain regions. Conversely, the slower adoption dynamics in the Central and Southwestern regions could be attributed to structural differences in farming systems, where traditional varieties fulfil specific cultural or market needs, thereby reducing the incentive for rapid transitions to new varieties. These varied regional patterns underscore the complexity of banana varietal dynamics in Uganda, revealing a delicate balance between tradition, innovation, stability, and adaptation. This balance is crucial for understanding the evolution of the varietal diversity across countries. The interplay between national trends, regional variations, and underlying structural factors provides a comprehensive picture of banana varietal dynamics in Uganda, highlighting the intricate balance between the various influencing elements.

CONCLUSIONS

The findings of this study provide valuable insights into the complex dynamics of banana varietal diversity and its adoption patterns in Uganda. The observed regional variations in diversity indices and adoption rates highlight the intricate interplay between agronomic, cultural, and economic factors that influence farmers' decisions. These patterns underscore the importance of considering the local context when developing strategies for banana variety management and improvement.

The cautious approach to adopting improved varieties, characterised by gradual integration rather than wholesale replacement, reflects farmers' risk management strategies and the cultural significance of traditional cultivars. This balance between innovation and tradition emphasises the need for breeding programs that prioritise both agronomic performance and consumer preferences to ensure sustainable uptake of improved varieties.

The regional disparities in varietal turnover rates and adoption behaviours reveal the multifaceted nature of the factors driving these trends, including environmental conditions, market linkages, and

structural elements such as access to clean planting materials. These findings have important implications for policymakers and agricultural researchers, suggesting that tailored approaches are necessary to address the specific needs and challenges of different regions in Uganda.

This study contributes to a deeper understanding of the banana cultivation landscape in Uganda by highlighting the delicate balance between stability and adaptation in varietal dynamics. Future research and development efforts should consider these complex interactions to promote sustainable and resilient banana farming systems that meet agronomic and socioeconomic objectives.

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APPENDICES

APPENDIX 1: REASONS FOR ADOPTING, DROPPING AND INTENDING TO DROP

Region	Reasons for Adopting Varieties	Reasons for Dropping Varieties	Reasons for Intending to Drop Varieties
Eastern	Drought tolerance, Early maturity, Fingers-compacted fingers (banana), High market demand, High yield, Pest and disease resistance/tolerance, Popularity among fellow farmers, Taste (good taste), Ability to take long without degenerating, Adaptability to the local environment, Bunch - big bunch (banana), Cooking quality (bread/ugali, baking, frying, boiling, etc.), Low cost of maintenance, Dormancy period, Processing quality (starch content), High dry matter, Strong stem	Bad taste, Fibrous (has threads), Late maturity (takes too long to mature), Low dry matter, Low market demand, Yield- low yield, Poor suckering ability (banana), Small bunches (banana), Short fingers (banana), Susceptible to Pests and Diseases, cannot easily adapt to current environment	Low market demand, Yield- low yield, Small bunches (banana), Susceptible to Pests and Diseases, Cannot easily adapt to current environment, Late maturity (takes too long to mature), Bad taste, Hard when boiled, Poor processing quality/cookability, Short fingers (banana), Too much suckering (banana)
Central	High market demand, High yield, Early maturity, Pest and disease resistance/tolerance, Taste (good taste)	Difficulty in obtaining clean planting materials, Low market demand, Susceptibility to drought, Susceptibility to Pests and Diseases, Yield- low yield, Short fingers (banana), Small fingers (banana), Cannot easily adapt to current environment, Soil infertility, Bad taste, Lack of operating capital/finance	Low market demand, Yield- low yield, Small bunches (banana), Susceptible to Pests and Diseases, Cannot easily adapt to current environment, Short fingers (banana), Small fingers (banana), Soil infertility, Substituted with a better variety, Rots faster (short shelf life), Ripens too quickly/highly perishable, Bad taste, Fingers easily break off (banana)
South Western	No data reported	Low market demand, Bad taste, Yield- low yield, Late maturity (takes too long to mature), Susceptible to Pests and Diseases, Religious belief, Cannot easily adapt to current environment, Difficulty in obtaining clean planting materials	Low market demand, Yield- low yield, Susceptible to Pests and Diseases, Susceptible to drought, Late maturity (takes too long to mature), Bad taste, Poor processing quality/cookability, Rots faster (short shelf life), Ripens too quickly/highly perishable, Difficulty in obtaining clean planting materials, Too sweet, Poor suckering ability (banana)
Western	No data reported	Low market demand, Susceptible to drought, Susceptible to Pests and Diseases, Yield- keeps reducing with time (degrades faster), Animals (mostly destroyed by livestock)	Low market demand, Yield- low yield, Susceptible to Pests and Diseases, Susceptible to drought, Cannot easily adapt to current environment, Late maturity (takes too long to mature), Small bunches (banana), Small fingers (banana), Animals (mostly destroyed by livestock)
Northern	Fingers - big fingers (banana), Fingers-compacted fingers (banana), High market demand, High yield, Pest and disease resistance/tolerance, Early maturity, Cooking quality (bread/ugali, baking, frying, boiling, etc.), Strong stem	Low market demand, Susceptible to Pests and Diseases, Yield- low yield, Bad taste, Lack of operating capital/finance	Low market demand, Yield- low yield, Susceptible to Pests and Diseases, Bad taste, Late maturity (takes too long to mature), Too soft when boiled

West Nile	Bunch - big bunch (banana), Early maturity, High market demand, High yield, Pest and disease resistance/tolerance, Taste (good taste), Drought tolerance, Low cost of maintenance	Low market demand, Susceptible to Pests and Diseases, Late maturity (takes too long to mature), Expensive to manage (requires a lot of financial investment), Bad taste	Low market demand, Yield- low yield, Small bunches (banana), Susceptible to Pests and Diseases, Late maturity (takes too long to mature), Small fingers (banana), Yield keeps reducing with time (degrades faster)