**Socio-Demographic Factors Influencing Banana Seed Demand among Smallholder Farmers in Uganda: A Cluster Analysis**

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## Abstract

Seed systems facilitate farmers' access to desirable crop cultivars; hence, a means of investment in improved and adaptable cultivars, and the delivery of genetic gains from breeding and selection of crops. They also support plant health security by using clean planting materials to minimise seed degeneration. Sustainable seed systems must align with the needs of farmers, while presenting opportunities for seed producers to sustain seed supply. Understanding the underlying factors influencing seed demand can enhance the efficiency of banana seed systems to meet the diverse context-specific needs of farmers. Therefore, this study investigates the sociodemographic factors affecting smallholder farmers' perceptions of banana seed demand and their seed acquisition behaviour in Uganda. Understanding the perceived seed demand and seed acquisition patterns could reveal the determinants of banana seed demand. A cluster-based approach was used to study these factors and provide insights into the determinants of off-farm seed sourcing. Multinomial and Tobit regression models were applied to data from 137 banana farmers in Central and Eastern Uganda. Banana seed demand is influenced by both the physical availability of seeds and farmers' sociodemographic characteristics. We identified three farmer clusters with varying perceived seed demands. Perceived seed demand influences farmers' information-seeking behaviour and seed source diversification, shaping their acquisition strategies. Income, household size, and the sex of the household head were significant predictors of perceived seed demand. A unit increase in income led to a 21.26 unit increase in perceived seed demand ($p < 0.001$). With each additional household member, the perceived seed shortage reduced by 12.78 units ($p = 0.041$). Male-headed households experienced a 55.86 units greater perceived shortage than female-headed households did ($p = 0.001$). These results reveal the underlying heterogeneity in seed demand determinants, which could shape farmer-centric and gender-transformative interventions that address the heterogeneity of smallholder farmers and advocate for a comprehensive multidimensional approach to improve banana seed systems. Our cluster-based analysis introduces a novel approach to studying banana and VPC seed systems.

**Key Words:** Banana, VPC seed systems, socio-demographic factors, gender, seed demand, cluster analysis, Uganda

## Introduction

Seed systems provide a pathway for investment in improved, adaptable, and preferred crop cultivars, thus taking advantage of genetic gain delivered through breeding and selection of crops. Seed systems are also important in ensuring the delivery of clean planting materials, maximising the genetic ability of the material used by minimising the drawback of seed degeneration. To maximise the adoption of improved crop varieties, vegetatively propagated crop (VPC) seed systems must align closely with the needs of the farmers (Almekinders et al., 2019). Access to and utilisation of VPC varieties is a recognised pathway out of poverty for smallholder farmers because of their potential to enhance productivity, climate resilience, and economic returns (Afionis et al., 2021; Akankwasa et al., 2021). However, formal seed systems for vegetatively propagated crops struggle to achieve a sustainable adoption level that would support widespread sustainability, use, and benefits (McEwan et al., 2023).

Like most developing countries, banana seed systems in Uganda are dominated by informal seed exchanges and some formal seed players, especially those dealing in a few cultivars, but also a hybrid of the two systems side by side. The formal banana seed system focuses on disseminating improved varieties that offer a greater yield, disease, and climate resilience. These new varieties often fail to address established farmer preferences, such as organoleptic properties and seed adaptability, resulting in widespread unacceptance among smallholder farmers. In addition, the seed trade is often misaligned with traditional views of seed acquisition methods through community barters and the characteristics used to evaluate seed quality. Most smallholder farmers rely on seeds from their fields or neighbouring farms, which are more accessible but often lack high-quality seeds, negatively affecting production (Ariho et al., 2015; Nduwimana et al., 2022). Informal sourcing restricts access to improved cultivars, which are initially available through formal channels and lead to seed degeneration. Financial constraints, limited awareness, and logistical issues impede access to high-quality seeds from formal sources (Kilwinger et al. 2020). Furthermore, formal sources may offer less adaptable materials requiring meticulous management than informal system suckers. Despite the development of seed system interventions, there remains an unmet need for strategies tailored to the diverse sociodemographic profiles of smallholder farmers (McEwan et al., 2023; Ssewanyana et al., 2020).

This misalignment limits the effectiveness of seed system interventions and underscores the need for a demand-driven approach to seed systems. It also underscores an unmet need for seed system interventions that are not only responsive to agronomic performance but also to the socio-cultural and economic realities of different farmer groups, an aspect currently overlooked in seed system development. Enhancing the banana seed system for Ugandan farmers requires an understanding of the socio-demographic factors that influence access. Despite the recognition of socio-demographic factors influencing agricultural practices, there remains a gap in understanding how these factors specifically affect banana seed demand and acquisition behaviour among smallholder farmers in Uganda. Existing research on banana seed systems has primarily concentrated on systemic barriers and general socioeconomic challenges, leaving a critical gap in understanding the influence of sociodemographic factors such as sex, household size, and income levels on banana farmers' seed access strategies (Marimo et al., 2020).

The absence of a comprehensive understanding of these sociodemographic factors impedes the development of tailored seed system solutions for smallholder farmers. Efficacious interventions necessitate the consideration of socio-demographic characteristics that influence seed demand and acquisition behaviours. Existing research indicates that seed acquisition is influenced by social networks, trust, cultural practices, and economic realities (Kilwinger et al., 2017; Mulugo et al., 2023) but often disregards socio-demographic differences. A clear knowledge gap exists in understanding the intricate ways in which sociodemographic factors such as age, gender, and household income influence smallholder farmers' perceptions of banana seed shortages and their subsequent seed acquisition behaviours. Our study seeks to bridge this gap by providing detailed insights into these dynamics.

This study investigated the sociodemographic factors influencing smallholder farmers, specifically smallholder farmers’ perceptions of banana seed demand and seed acquisition behaviours. We examined the relationship between farmers’ sociodemographic characteristics, perceived seed demand, and seed acquisition behaviours using perceived seed shortage as a proxy for banana seed demand. We used a cluster-based approach to analyse variations in farmers’ perceptions and the influence of sociodemographic characteristics. The cluster-based analysis represents a novel approach in the context of Uganda’s banana seed systems research, to identify the varied sociodemographic profiles of smallholder farmers and their unique seed system needs. The following research questions were addressed.

1. How can clustering based on sociodemographic factors enhance the understanding of farmer characteristics for tailored seed system interventions?
2. How do cluster-specific perceptions of seed demand influence seed acquisition behaviour?
3. What sociodemographic determinants shape farmers' perceptions of banana seed demand?

By identifying context-specific factors influencing banana seed demand, this study aims to inform farmer-centred banana seed system interventions. By employing a cluster-based analysis, this study offers a methodological advancement in tailoring seed system interventions to the diverse sociodemographic profiles of smallholder farmers, a need that has remained unmet by existing studies. Cluster analysis allowed us to uncover previously overlooked drivers of seed demand and acquisition, thereby offering a pathway to more inclusive and effective seed system interventions. This study contributes to the development of tailored VPC seed systems that address the distinct needs of various farming groups.

## Materials and methods:

### Study area

This study emanates from a broader study conducted in Central and Eastern Uganda to understand the dynamics of VPCs seed access and decision making at the household level. Three VPCs–banana, sweet potato, and cassava–were included in the study. Data collection took place in November and December 2023 in the districts of Nakaseke in the central region, and Kamuli and Bugiri in the eastern region. These districts are known to grow all three VPCs in terms of food and income.

### Sample Determination

Sample size was determined using the following formula described by Yamane (1964):

$$n=\frac{N}{(1+N)*(e*e)}$$

Where:
N: the total population of the study area,
e: is the level of significance (limit of tolerable error)
n: The sample size

Given that 80% of Uganda's households are engaged in agriculture and considering a total of 4,046,723 households in Eastern and Central Uganda, the sample size was estimated to be 385 and equally distributed across the two study regions (Table 1).

### Sampling Strategy

Regions, districts, sub-counties, and parishes were selected purposively based on three criteria: 1) at least one of the VPCs was a major crop: Nakaseke was banana, Cassava for Bugiri, and sweet potato for Kamuli; 2) the importance of the VPCs to livelihoods (food and income); and 3) participation in preliminary trials for improved VPC varieties. Comprehensive household lists were generated within the selected parishes, with the help of agricultural extension officers and local community leaders. The farmers' lists were stratified by VPC to ensure an equal representation of all categories. The participating farmers were randomly selected from the stratified lists.

### Data Collection

This study adopted a mixed-methods approach, and data were collected using structured questionnaires, Focus Group discussions (FGDs) and key informant interviews. A total of 364 farmers were interviewed using structured questionnaires, representing a 95% response rate that significantly exceeded the 70% threshold recommended by Amin (2005). The Structured questionnaires were automated using the Open Data Kit (ODK) platform via ODK Build (Anokwa et al. 2009). These were deployed to research assistants who conducted interviews using ODK Collect, with the data securely stored on the ODK Aggregate. Twenty-four (24) sex and age-disaggregated FGDs and ten (10) were conducted to collect data on seed access, decision-making, access to information, and seed delivery structured along the lines of the ladder of life (Petesch, 2018).

### The focus of this paper

This paper focuses on the banana VPC utilising data from only 137 respondents for whom bananas were the main VPC cultivated (Table 1). The analysis was based on the data obtained from structured questionnaires completed by 137 banana farmers.

***Table 1: Sample distribution, response rate, and farmers for whom banana was the main VPC.***

| *Region* | *District* | *Sub-county* | *Sample* | *Respondents* | *Response rate* | *Banana as the main VPC* |
|---|---|---|---|---|---|---|
| ***Eastern*** | Bugiri | Buwunga | 48 | 45 | 94% | 22 |
| | | Nabukalu | 48 | 45 | | |
| | Kamuli | Nabwigulu | 48 | 46 | 97% | 33 |
| | | Namwendwa | 48 | 47 | | |
| ***Central*** | Nakaseke | Kikamulo | 96 | 90 | 94% | 82 |
| | | Nakaseke | 97 | 91 | | |
| | | **Total** | **385** | **364** | **95%** | **137** |

### Data Variables

The key variables and their definitions, measurements, and roles used in this study are detailed in Table 2 to provide a basis for empirical analysis. The dependent variable was perceived seed shortage level, which was a continuous variable between 0 and 100 (% of seeds planted vs. desired). The independent variables were as follows:

***Table 2: Study Variables***

| *Variable name* | *Type of Variable* | *Observation* |
|---|---|---|
| ***Age group*** | categorical | 18-35 years; 36-49 years, 50-60 years, above 60 years |
| ***Household size*** | continuous | Number of people per HH |
| ***Education level*** | Categorical | None, Primary (P1-P7), Secondary (O-Level), Secondary (A-Level), Diploma or Degree |
| ***Marital Status*** | Nominal | Married, Never Married, Separated/Divorced, Widowed |
| ***Perception of wealth status in the community*** | Categorical | 'Better-off than most people', Same as others, Worse off than others |
| ***Sex the Household head*** | Nominal | Male or female |
| ***Access to information on VPC*** | Nominal | Yes or No |
| ***Land size allocated to VPC*** | Continuous | Land size in acres |

| | | |
|---|---|---|
| ***Experience seed shortage*** | Nominal | Yes or No |
| ***Income level in UGX (USD)*** | Categorical | ≤ 500,000 (130), 501,000 ≤ x ≤ 1M (131 ≤ x ≤ 260), 1M ≤ x ≤ 6M (261≤ x ≤ 1,580), 6M ≤ x ≤ 20M (1,581≤ x ≤ 5,280), >20M (>5,280). |
| ***Sourcing Seed from multipliers*** | nominal variable | Yes or No |

## Data Analysis Procedure

Data collected using ODK were downloaded from the ODK aggregate into SPSS, STATA, and Excel for cleaning, exploration, and analysis. Descriptive statistical analysis was performed to explore the data and develop a cluster analysis of farmers based on their sociodemographic and economic characteristics. Inferential statistical analysis was performed to establish the cause-effect relationship between variables using Spearman correlation and a binary logistic regression model.

## Farmer Clustering

Two-step clustering, combining K-means and Hierarchical techniques, was employed for its efficiency in handling large datasets with mixed variables, including categorical, nominal, ordinal, and continuous types (Hair et al., 2013). In the first step, the K-means algorithm divides the dataset into smaller pre-clusters based on similarities, thereby improving computational efficiency. These pre-clusters were then used as inputs for hierarchical clustering in the second step, which further refined the grouping. The clustering process is guided by the following formula:

$$\mu_j = \frac{1}{|C_j|} \sum_{x_i \epsilon C_j}^{n} x_i$$

Each data point was assigned to a pre-cluster to minimise the distance from the cluster centres. The second step, involving hierarchical clustering (cluster aggregation), treats the pre-clusters as data points, thereby facilitating the identification of cluster structures within a larger dataset. To assess cluster quality, the silhouette measure of cohesiveness was calculated according to the method of Kaufman and Rousseeuw (1990). Silhouette values were interpreted as follows: values up to 0.2 indicate poor cohesion, values between 0.2 and 0.5 suggest fair cohesion and values above 0.5 are considered good.

The variables in each developed cluster were weighted using the Maximum Entropy Principle (Aldana-Bobadilla et al., 2015), with the entropy of a probability distribution P(x) for a discrete variable x, calculated as

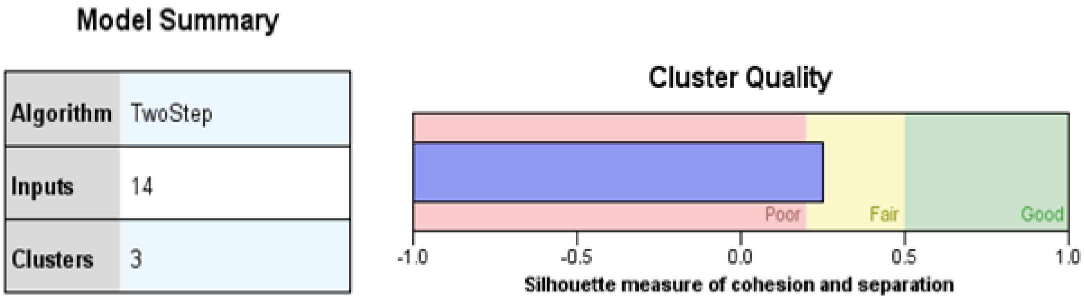
$$E = -\sum\left(p_i * log_2(p_i)\right)$$

Where P$i$ is the proportion of each category within the cluster.

According to Aldana-Bobadilla et al. (2015), lower entropy values indicate higher cohesiveness within a cluster. In line with Luna-Romera et al. (2018), clusters with a standard deviation of entropy values of 0.5 or less were considered to exhibit strong cohesiveness and homogeneity.

### Clustering Model Summary

The silhouette measure of cohesion and separation was estimated to be 0.3, indicating moderate clustering quality according to Kaufman and Rousseeuw (1990). Although there was potential for improvement in both cohesion and separation, the clusters demonstrated reasonable internal consistency and distinctiveness.




### Multinomial Regression Analysis

To examine the relationship between farmers' reported seed shortages and their seed-sourcing behaviours, a multinomial regression analysis was performed. To account for variations among farmer groups, analyses were conducted for the entire dataset and separately for each cluster. Smeden et al (2017) suggests that the use of multinomial logistic regression models is advocated for modelling the associations of covariates with three or more mutually exclusive outcome categories. Therefore, a multinomial regression model was applied to each dependent variable (seed sources, seed-related information sources, seed-related decision making, and seed types grown), with the reported seed demand as the independent variable. The following equations describe the general structure of the model:

$$P(Y=k\backslash X) = \frac{\exp(\beta_{ko}+\beta_{k1}X)}{\sum_{j=1}^{K}\exp(\beta_{jo}+\beta_{j1}X)}$$

P(Y=k\X): Probability of selecting category k for the dependent variable given perceived seed shortage X

$\beta_{ko}$: intercept for category k

$\beta_{k1}$: Coefficient for the effect of perceived seed demand (X) on category k

The Log-Odds of Selecting a Seed Source Relative to a Reference Category is determined by the following equation

$\text{Log}\ (\frac{P(Y=k\backslash X)}{P(Y=K\backslash X)}) = \beta_{ko} + \beta_{k1}X$

$\text{Log}\ (\frac{P(Y=k\backslash X)}{P(Y=K\backslash X)})$ Log-odds of choosing seed source k relative to the reference category K.

Odds ratios were calculated as follows:
Odds Ratio=exp$\beta_{k1}X$

represents how a one-unit increase in the perceived seed shortage (X) changes the odds of selecting category k relative to the reference category.

### Correlation Analysis and Tobit Regression Model

A correlation matrix and Tobit regression analysis were used to establish the cause-effect relationship between the variables. The Pearson correlation was calculated using Spearman's formula (1930):

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

Where:

- $d_i$ is the difference between the ranks of each pair of observations for the two variables,
- *where n denotes* the number of pairs of observations.

The $r_s$ values ranged from -1 to +1.

- $r_s$=+1: perfect positive monotonic correlation.
- $r_s$= -1: Perfect negative monotonic correlation.
- $r_s$= 0: no monotonic correlation.

A Tobit regression model was adopted to assess the determinants of seed demand as an indicator of demand. This model was suitable because the dependent variable (seed shortage) was right-censored, ranging from 0 to 100, with 74 of the 137 observations reaching the upper limit (Amore,2021).

Tobit regression assumes a linear relationship between the latent variable (Y∗Y∗) and independent variables:

$$Y^* = \beta_0 + \beta_1X_1 + \beta_2X_2 + \cdots + \beta_kX_k + \varepsilon$$

Where:
$Y^*$=is the unobserved latent variable
$\beta_0$ is the intercept.
$\beta_1, \beta_2\ldots, \beta_k$ are the coefficients for the predictors $X_1, X_2,\ldots,X_k$

$\varepsilon$= a normally distributed error term.

The model was estimated using STATA version 15, statistical software widely used for econometric analyses. The dependent variable, seed shortage, represents the percentage of seeds that a farmer can access, with values bounded between 0 and 100%. The observed variable $Y_i$ is defined as follows:

$$Y_i = \begin{cases} 0 & \text{if } Y_i^* \leq 0 \\ Y_i^* & \text{if } 0 < Y_i^* < 100 \\ 100 & \text{if } Y_i^* \geq 100 \end{cases}$$

## Results

### 1. Respondent Characteristics

The analysis commenced with an examination of respondents' demographic characteristics, which constituted the foundation for clustering. Table 3 presents a comprehensive overview of these characteristics.

*Table 3: Sociodemographic characteristics of the respondents*

| ***Variable*** | ***Observations*** | ***Districts*** | | | |
|---|---|---|---|---|---|
| | | Nakaseke (%) | Bugiri (%) | Kamuli (%) | Frequencies (%) |
| ***Sex of the Household head*** | Male | 58 (42) | 16 (12) | 29 (21) | 103 (75) |
| | Female | 2 (18) | 24 (4) | 6 (3) | 34 (24) |
| ***Age of respondent*** | 18-35 years | 34 (25) | 6 (4) | 10 (7) | 50 (36) |
| | 36-49 years | 24 (18) | 5 (4) | 10 (7) | 39 (28) |
| | 50-60 years | 15 (11) | 6 (4) | 7 (5) | 28 (20) |
| | Above 60 years | 9 (7) | 5 (4) | 6 (4) | 20 (15) |
| ***Education level of the respondent*** | None | 4 (3) | 0 | 1 (0.7) | 5 (4) |
| | Primary (P1-P7) | 45 (33) | 12 (9) | 18 (13) | 75 (54) |
| | Secondary (O-Level) | 28 (20) | 6 (4) | 11 (8) | 45 (33) |
| | Secondary (A-Level) | 1 (0.7) | 4 (3) | 0 | 5 (4) |
| | Diploma or Degree | 4 (3) | 0 | 3 (2) | 7 (5) |
| ***Marital Status of respondent*** | Married | 62 (45) | 16 (12) | 28 (20) | 106 (77) |
| | Not married | 5 (4) | 2 (2) | 0 | 7 (5) |
| | Widowed | 7 (5) | 4 (3) | 2 (2) | 13 (9) |
| | Separated/ Divorced | 8 (6) | 0 | 3 (2) | 11 (8) |
| ***Perceived Wealth Status in the Community*** | Better off than other people | 19 (14) | 6 (4) | 8 (6) | 33 (24) |
| | Same as others | 38 (28) | 13 (10) | 12 (9) | 63 (46) |
| | Worse-off than others | 25 (18) | 3 (2) | 13 (10) | 41 (30) |
| ***Average Annual Income of household in UGX (USD)*** | $\leq$ 500,000 (130) | 7 (5) | 2 (2) | 0 | 9 (7) |
| | 501,000 $\leq$ x $\leq$ 1M (131 $\leq$ x $\leq$ 260) | 18 (13) | 6 (4) | 9 (7) | 33 (24) |
| | 1M $\leq$ x $\leq$ 6M (261$\leq$ x $\leq$ 1,580) | 45 (33) | 13 (10) | 23 (17) | 81 (59) |
| | 6M $\leq$ x $\leq$ 20M (1,581$\leq$ x $\leq$ 5,280) | 11 (8) | 1 (0.7) | 1 (0.7) | 13 (9) |
| | >20M (>5,280) | 1 (0.7) | 0 | 0 | 1 (0.7) |

| | | | | | |
|---|---|---|---|---|---|
| ***Household Size (No of people per HH)*** | 1-3 | 21 (15) | 0 | 1 (0.7) | 22 (16) |
| | 4-5 | 28 (20) | 3 (2) | 6 (4) | 37 (27) |
| | 6-9 | 29 (21) | 12 (9) | 18 (13) | 59 (43) |
| | 10+ | 4 (3) | 7 (5) | 8 (6) | 19 (14) |
| ***Source seed from multipliers*** | No | 18 (13) | 3 (2) | 9 (7) | 30 (22) |
| | Yes | 64 (47) | 19 (14) | 24 (18) | 107 (76) |
| ***HH member who accesses seed-related information*** | Female | 30 (22) | 7 (5) | 8 (6) | 45 (33) |
| | Male | 33 (24) | 12 (9) | 16 (12) | 61 (44) |
| | Both male and female | 19 (14) | 3 (2) | 8 (6) | 30 (22) |
| | Everyone at home | 0 | 0 | 1 (0.7) | 1 (0.7) |
| ***Perceived Seed shortage*** | Average | 47.3 | 51.53 | 40.24 | 75 |
| | Maximum | 80 | 90 | 70 | 100 |
| | Minimum | 10 | 17 | 10 | 10 |

The study participants varied in household structure, income level, marital status, education, and self-assessed wealth status. Most were in male-headed households, aged 36–49 years, had completed primary education, and were married. The participants in Nakaseke district perceived themselves as more affluent than those in Bugiri and Kamuli districts. Most earned an annual income ranging from UGX 1 million to UGX 6 million, with very few exceeding this range. Households vary in size and usually comprise six to nine members. More male than female farmers have access to banana seed information. Bugiri district reported the highest banana seed demand, followed by the Nakaseke and Kamuli districts.

## 2. Farmer Clustering

We identified three clusters of banana farmers, using 14 variables (Table 4). A silhouette score of 0.3, was sufficiently high to proceed with the clustering analysis. These clusters represent distinct farmer profiles. They are based on demographic, economic, and banana farming traits.

*Table 4: Summary of characteristics defining the clusters*

| *Variables* | *Cluster 1 (47%)* | *Cluster 2 (18%)* | *Cluster 3 (35%)* |
|---|---|---|---|
| *Av land size allocated to banana (acres)* | 1.1766 | 0.8452 | 0.9125 |
| *District Distribution (%)* | Nakaseke (50) and Kamuli (31) | Nakaseke (72); Bugiri (16); Kamuli (12) | Nakaseke (66); Bugiri (13) |
| *Age group (%)* | 36–49 years (50); >50 years (50) | >50 years (64); 28% 36–49 years (28); 18-35 years (8) | 18–35 years (100) |
| *Completed primary education (%)* | 96 | 68 | 100 |
| *Dominant Marital Status (%)* | Married (94) | Single (80) | Married (85) |
| *Farming as Primary occupation (%)* | 92 | 84 | 88 |
| *Dominant self-assessed wealth status (%)* | Same as others in the community (42) | Worse-off (48). | Same as others in the community (54) |
| *Dominant Annual Income bracket in UGX (%)* | 1–6 million (61) | 0-1million (52) | 1–6 million (63) |
| *>6 members in the HH (%)* | 76 | 40 | 40 |
| *Dominant sex of Household Head (%)* | Male-headed (97). | Female-headed (100) | Male-headed (88) |

| | | | |
|---|---|---|---|
| *% growing improved cultivars* | 43 | 36 | 46 |
| *% reporting Seed Demand* | 56 | 24 | 44 |
| *% owning permanent houses* | 88 | 80 | 60 |

Each cluster was labelled to demonstrate uniqueness. A detailed description of each cluster is provided below:

***Cluster 1:*** *Middle-aged males owned the largest banana plots on average, and more than half of them experienced banana seed demand.*

This cluster mainly consisted of male farmers (97%), with an average banana plantation size of 1.1766 acres. Fifty % of the farmers in this cluster were from Nakaseke District and 31% were from Kamuli District, with no representation from Bugiri District. Half of them were aged 36–49 years, and the rest were over 50 years. 94% of the farmers were married, and farming was the main occupation for 92% of them. Regarding education, 56% had completed primary education, 31% had completed secondary education, and approximately 9% held a diploma or degree. Regarding the self-assessed wealth status, 42% considered themselves to be like other farmers, 32% perceived themselves as better off, and 25% believed they were worse off. 61% of farmers reported annual earnings between UGX 1-6 million, with 14% earning above UGX 6 million. Of households with more than six members, 97% were male-headed. Among the cultivars grown, 56% cultivated only local cultivars, 10% cultivated only improved cultivars, and 34% cultivated both local and improved cultivars. 56% of the farmers experienced banana seed demand and 88% resided in their own permanent houses.

***Cluster 2:*** *Older Females, owning the smallest banana plots on average and <quarter experience banana seed demand*

This cluster consisted mainly of female farmers (96%) with an average banana plantation size of 0.8452 acres. Most (72%) of the farmers in this cluster were from Nakaseke district, with smaller proportions from Bugiri (16%) and Kamuli (12%). 64% were over 50 years old, 28% were 36–49 years old, and 8% were 18–35 years old. Most (80%) of these farmers were single, widowed (48%), separated (24%), or never married (8%); farming was the main occupation (84 %). In terms of education, 68% had completed primary education, with none holding a diploma or a degree. Regarding self-assessed wealth, 48% perceived themselves as being worse off, whereas 52% considered themselves on par with others. The annual income of 36% was between UGX 500,000 and 1 million (36%), and 46% earned UGX 1–6 million. No farmer in this cluster earned UGX 6 million. This cluster comprised only female-headed households, with 60% having fewer than five members. Most (64%) grew local cultivars only, 4% grew improved cultivars only, and 32% grew both local and improved cultivars. A small proportion (24%) experienced seed demand and 80% resided in their own permanent houses.

***Cluster 3:*** *Younger farmers, owning moderate-sized banana plots and nearly half experience banana seed demand*

This cluster comprised 88% males with an average banana plantation size of 0.9125 acres. 66% of the farmers in this cluster are from Nakaseke District and 13% are from Bugiri District, with no representation from Kamuli District. They were aged 18-35 years and 81% were married. 10% were never married and 5% were divorced. The primary occupation was farming (86 %). In terms of education, 46% had completed primary education, 44% had completed secondary education, and approximately 10% held diplomas or degree qualifications. Regarding the self-assessed wealth status, 54% considered themselves to be at the same level as other farmers, 18% viewed themselves as better off, and 27% as worse off. 63% reported earnings between UGX 1-6 million annually, with 27% earning between UGX 500,000 and 1 million. 88% belonged to male-headed households, and the household size varied: 31% had one to three members, 24% had four to five members, and 39.5% had more than six members. Among the banana cultivars, 50% grew only local cultivars, 10% grew only improved cultivars, and 40% grew both local and improved cultivars. 44% of the farmers reported experiencing banana seed demand, 60% lived in their own permanent houses, 21% rented, and 16% lived in their own semi-permanent houses.

**Cluster Validity and Cohesiveness**

The minimum entropy values indicated that the clusters were valid and cohesive, representing groupings based on shared characteristics, while capturing variability. Cluster 2 exhibited the highest homogeneity, demonstrating low entropy in wealth status, banana cultivar grown, and the sex of the household head suggesting a well-defined and consistent group. By contrast, Cluster 3 displayed greater heterogeneity, with higher entropy in variables such as district and wealth status, indicating the inclusion of farmers with diverse attributes. Cluster 1 demonstrated moderate variability, balancing uniformity and diversity in variables such as household size and income. The low standard deviation, at 0.44" 0.56, supported the internal consistency of the clusters, while maintaining distinction among them. These patterns provide evidence for the validity of the clustering process and its capacity to capture meaningful farmer groupings.

*Table 5: Cluster weighting based on minimum entropy within clusters*

| ***Variable*** | ***Cluster 1 Entropy*** | ***Cluster 2 Entropy*** | ***Cluster 3 Entropy*** |
|---|---|---|---|
| *Demand of banana Seed* | 0.983 | 0.835 | 1.061 |
| *District* | 1.445 | 1.252 | 1.564 |
| *Banana Cultivars grown (Local vs. Improved)* | 1.015 | 0.767 | 1.06 |
| *Age Category (Youth or Adult)* | 0.329 | 0.725 | 0.057 |
| *Highest Level of Education* | 2.547 | 1.719 | 2.089 |
| *Marital Status* | 1.267 | 1.316 | 1.34 |
| *Primary Occupation* | 1.933 | 1.5 | 1.451 |
| *Wealth Status* | 1.479 | 1.263 | 1.573 |
| *Household Size* | 1.524 | 1.771 | 1.773 |

| | | | |
|---|---|---|---|
| *Average Annual Income* | 1.88 | 1.276 | 1.592 |
| *Sex of Household Head* | 0.938 | 0.294 | 0.945 |
| *Decision making* | 1.434 | 1.44 | 1.523 |
| ***Standard Deviation*** | **0.56** | **0.44** | **0.52** |

## 3. The influence of perceived seed demand on seed-acquisition behaviour

46% of the farmers reported experiencing seed demand in the previous year. Farmers in different clusters had varied views on banana seed shortage. Cluster 1 had the most (56%) farmers reporting seed demand. Cluster 3 followed at 44%, and cluster 2 had the lowest incidence at 24%. We examined how these perceptions influenced farmers' access to banana seeds. We focused on the sources of seed information, seed sources, and the cultivars chosen. We also examined whether perceived seed shortage influences the sex of the person who makes seed-related decisions in the household. We found patterns in farmers' behaviours, with variations between clusters, despite the lack of statistical significance.

### 3.1. The influence of perceived seed demand on Seed Information Sources

There was no significant relationship between information sources and perceived seed demand across the clusters. However, the Exp(B) analysis showed patterns in information-seeking behaviour. The media was a reliable source of seed information across all clusters, but secondary sources varied. For Cluster 1, extension services and research institutions such as NARO played a role in disseminating information. Given that Cluster 1 reported the highest seed shortage incidence, this behaviour may suggest that farmers seek help when they perceive a seed shortage. Conversely, in Cluster 2, which had the lowest seed shortage incidence, farmers primarily relied on neighbours for seed information, indicating a stronger dependence on informal networks, perhaps because of a lower sense of urgency.

### 3.2. The influence of perceived seed demand on Seed Sources used by the farmers

Farmers across all clusters mostly relied on their own gardens and other farmers' fields as primary sources of banana seeds. The relationship between perceived seed shortage and the choice of seed source was not significant, but Cluster 2 showed a marginal significance (p=0.051). In Cluster 1, notable reliance on extension services and research institutions as seed sources was observed, complementing the trend in information sources. Farmers in Clusters 1 and 3 showed similar patterns. They use a combination of community and formal seed sources. There was also a decline in the use of seeds from farming fields. These results suggest that perceived seed demand may subtly influence the choice of seed source, as observed in clusters with high seed demand.

### 4.4. The influence of perceived seed demand on Types of Cultivars Grown and Seed-Related Decision-making

Across all clusters, farmers primarily cultivated local cultivars which accounted for 90%–96 % of their farms. Farmer perception of seed demand did not influence the choice between local and improved cultivars, as evidenced by the low R-squared values and non-significant odds ratios. Regarding decision making, the analysis considered decisions on the quality and quantity of seeds, accompanying technology, and where and when to acquire seeds. In Cluster 1 which had the highest incidence of seed demand, the results showed moderate explanatory power. However, the lack of significance and unreliable odds ratios indicated that perceived seed demand was not a key factor influencing the sex of decision-makers in this context.

## 4. Sociodemographic Determinants of Farmer's Perceptions of Banana Seed Demand

### *4.1. Correlation Analysis Results*

Correlation analysis revealed several significant associations between sociodemographic factors and perceived seed shortage. There was a negative correlation between household size and perceived seed shortage ($r = -0.197$, $p < 0.05$). Larger households reported lower levels of seed shortage. The sex of the household head was positively correlated ($r = 0.189$, $p < 0.05$). Male-headed households reported higher levels of perceived seed shortage.

*Table 6: The relationship between perceived seed shortage and sociodemographic factors*

| | *Age Category* | *Wealth status* | *Av Income* | *HH Size* | *Sex of the HH* | *Type of seeds* | *Land size* | *Seed Multipliers* |
|---|---|---|---|---|---|---|---|---|
| *Age Category* | 1.000 | | | | | | | |
| *Wealth status* | -0.094 | 1.000 | | | | | | |
| *Average Income* | -0.057 | **-0.319**** | 1.000 | | | | | |
| *Household Size* | **0.329**** | -0.123 | 0.092 | 1.000 | | | | |
| *Gender of the HH head* | 0.119 | 0.116 | **-0.250**** | -0.103 | 1.000 | | | |
| *Type of seeds* | -0.087 | 0.011 | 0.040 | 0.152 | -0.058 | 1.000 | | |
| *Land allocated to banana* | 0.079 | **-0.272**** | **0.331**** | 0.054 | -0.099 | -0.024 | 1.000 | |
| *Seed Multipliers as a source of seeds* | -0.084 | 0.114 | -0.115 | 0.008 | -0.064 | **-0.273**** | 0.016 | 1.000 |
| *Perceived seed shortage* | -0.032 | -0.077 | 0.098 | -0.197* | **0.189*** | -0.071 | 0.086 | -0.020 |

***. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).*

### *4.2. Tobit Regression Analysis Results*

Tobit regression analysis showed that annual income, household size, and the sex of the household head were significant predictors of perceived seed shortage. The model that included 137 observations was significant (Likelihood Ratio chi-square = 15.36, df = 6, $p = 0.0177$). It has 63 uncensored and 74 right-censored data points. This shows that the predictors influence seed shortage perceptions at the 5% level.

The model found a strong link between income and perceived seed shortage. A 1-uit increase in income led to a 21.26-unit increase in perceived shortage ($p < 0.001$). While there was a weak correlation between perceived seed shortage and household size, the model showed a significant connection with a larger household size, decreasing the levels of perceived seed shortage. Larger households showed a 12.78-unit decrease in the perceived shortage for each additional member ($p = 0.041$). Male-headed households also had a 55.86-unit higher level of perceived seed shortage than female-headed households did ($p = 0.001$). The confidence intervals for the significant predictors (annual income: 10.05–32.48, household size: -25.01 to

-0.55, and gender of the household head: 23.71–88.01) supported the robustness of these findings. Other factors such as age, marital status, and wealth status did not show a connection with perceived seed shortage (p = 0.299, p = 0.279, and p = 0.981, respectively).

*Table 7: Variables in the Equation xxxxx please say more (Would it be good to have this aggregated for males and females?)*

| *Perceived Seed Shortage* | Coef. Std. | Err. | t | P>t | [95%Conf. Interval] | |
|---|---|---|---|---|---|---|
| *Age category* | 5.213312 | 4.997488 | 1.04 | 0.299 | -4.672912 | 15.09954 |
| *Marital Status* | -8.28557 | 7.618448 | -1.09 | 0.279 | -23.35668 | 6.785536 |
| *Wealth status* | 0.150153 | 6.219926 | 0.02 | 0.981 | -12.15435 | 12.45465 |
| *Annual income* | 21.26038 | 5.669168 | 3.75 | 0.00 | 10.04541 | 32.47534 |
| *Household Size Category* | -12.7768 | 6.181592 | -2.07 | 0.041 | -25.00543 | -0.5481 |
| *Sex of the household* | 55.85854 | 16.25131 | 3.44 | 0.001 | 23.70958 | 88.0075 |

## Discussion

### The role of clustering in improving the understanding of farmers' characteristics

Cluster analysis is essential for comprehending the attributes of farmers by revealing the distinct challenges faced by different groups. It is also vital to identify seed access patterns influenced by sociodemographic characteristics to provide profound insights into how they affect farmers' experiences.

Cluster 1 demonstrates that even affluent farmers with large landholdings encounter difficulties in obtaining adequate banana seeds despite their connections to formal seed sources, highlighting the systemic inefficiencies in the formal seed system. This elucidates how wealth and land size interact with seed accessibility, revealing systemic obstacles that may otherwise remain undetected. Cluster 2 emphasises the barriers faced by disadvantaged groups, particularly older, low-income women, who frequently lack access to resources such as extension services and research institutions, relying instead on informal seed sources and community networks. This underscores the intersection of socio-economic and demographic factors, particularly gender, in creating unique challenges for marginalised groups (Mutenje et al., 2021). Gender inequalities in seed access are evident, aligning with McGuire and Sperling's (2014, 2016) findings that older women face greater challenges in adopting agricultural innovations. The socioeconomic diversity in Cluster 3 illustrates the versatile strategies of farmers in response to the limitations of the banana seed system. Farmers in this group alternate between formal and informal systems, based on their resources and needs. As noted by Musa et al. (2022), farmer adaptability emphasises how income and resource availability influence seed access decisions and reveals distinct seed acquisition patterns.

Clustering farmers facilitates a more comprehensive understanding of how socioeconomic and demographic factors influence differential access to banana seeds, which is essential for designing targeted and equitable interventions. Clustering is crucial in VPCs, in which informal seed systems influence farmers' choices. By analysing farmers' sociocultural and economic characteristics, the effectiveness of seed systems can be enhanced, allowing for the tailoring of interventions to their specific needs. Kansiime and Mastenbroek (2016) emphasised the importance of balancing cultural preferences with market demands in seed systems, in which clustering helps to examine them more thoroughly.

**The influence of perceived seed demand on seed-acquisition behaviour**

Perceived seed demand shapes farmers' behaviour in acquiring banana seeds. Farmers tend to modify their seed acquisition strategies, influencing how they seek information, their reliance on formal or informal seed sources, and the cultivars they choose to grow.

In line with Mutenje et al. (2021), this study found that farmers are more likely to seek information from formal sources such as extension services and research institutions when they perceive higher levels of seed demand. This could be because formal sources are often viewed as credible and provide a sense of assurance. However, in situations where seed demand is not as strongly perceived, farmers tend to rely more on informal networks, such as neighbours, who are considered more immediate and familiar sources of information. This behaviour aligns with the findings of Almekinders et al. (2019), who noted that informal networks become more prominent when the urgency of a shortage is less perceived. This difference in information-seeking behaviour underscores the role of perceived seed demand in prompting farmers to explore different channels for information and assistance. This also highlights the variability in farmers' reliance on formal versus informal sources, which can vary depending on the perceived level of seed demand.

Perceptions of seed shortage also influence the sources from which farmers acquire seeds. Farmers who perceive a higher demand tend to diversify their sources and engage in both formal and informal seed systems. This could be important for mitigating the risk of seed shortage. By contrast, in situations where seed shortage is perceived to be low, farmers tend to rely primarily on informal sources that are more accessible and familiar to them. These patterns are consistent with the literature on seed system diversification, which suggests that banana farmers adopt multiple strategies to meet seed demand (Ortiz et al., 2016; Kansiime & Mastenbroek, 2016). Despite their potential to provide high-quality seeds, formal banana seed systems are often constrained by logistical challenges, price barriers, and limited availability in many regions of Sub-Saharan Africa. In such cases, informal seed systems play a critical role in ensuring seed security.

However, farmers' decisions regarding cultivar choice were less affected by perceived seed shortage. Local cultivars remained dominant across farming clusters. This suggests that factors other than perceived seed demand, such as the adaptability of local cultivars to specific environmental conditions, cultural preferences, and market demand, are more influential in shaping cultivar choice (McGuire & Sperling, 2021; McGuire & Sperling, 2016). This highlights the need for banana seed system interventions to not only focus on introducing new varieties, but also to strengthen the informal seed systems that support the continued use of local cultivars.

Although gender is often a critical factor in agricultural decision making, the influence of perceived seed demand on gendered decision making in this study was less pronounced. McGuire and Sperling (2014, 2016) suggest that resource scarcity often results in more women taking charge of seed-related decisions in certain contexts. However, in this study, the perceived shortage of seeds did not influence the sex of the person making seed-related decisions. This suggests that other factors, such as land ownership, economic status, and household dynamics, may play a more dominant role in gendered decision making within the banana seed system. Exploring the roles of both men and women in banana seed-related decisions and how these roles are influenced by broader socioeconomic conditions would provide a more comprehensive understanding of gendered behaviour in banana seed systems.

**Sociodemographic determinants of banana Seed demand**

The identified significant sociodemographic predictors of seed demand, measured by perceived seed demand, were income, household size, and sex of the household head. This shows that the farmers' demand for banana seeds is shaped by their sociodemographic characteristics.

The findings show that, as income increases, farmers perceive a greater seed shortage. High-income farmers tend to prefer high-quality banana seeds that are often limited (Ortiz et al. 2016). This trend may be linked to increased access to formal seed sources, as high-income farmers can afford seeds but still face the challenge of inadequate seed supply, specifically associated with formal sources. This implies that higher-income farmers may experience more complex seed-access issues when formal seed systems are underdeveloped.

Additionally, the negative correlation between household size and perceived seed shortage, wherein larger households reported lower seed shortage levels, suggests that resource pooling in larger households may provide better access to seeds. This finding demonstrates that larger households often have better capacity to adapt to agricultural challenges. Larger households may also diversify their crop portfolios which may act as a buffer against the effects of seed demand (McGuire & Sperling, 2016).

Regarding the sex of the household head, the significant relationship between male-headed households and higher levels of perceived seed shortage underscores the gendered dynamics of agricultural decision-making. This could imply that these households might be more attuned to formal seed systems, where seed demand is often more pronounced because these systems may focus on improved cultivars that are subject to supply issues. Furthermore, given the context in which local cultivars are preferred, female farmers may be better positioned to manage their seed sources through informal exchanges that influence their perceptions of seed demand (Kansiime & Mastenbroek, 2016).

## Conclusions

This study contributes to the growing body of literature on banana seed systems by highlighting the value of a clustering approach to understanding farmers' needs and advancing insights into smallholder farmers' demand for banana seeds.

This demonstrates the value of the clustering approach by revealing how different farmer groups face unique challenges when accessing banana seeds. This reveals the diversity in farmers' socioeconomic and demographic characteristics that influences their seed acquisition behaviour. By identifying these distinct groups, this study offers targeted insights into their specific needs and behaviours.

Regarding farmers' demand for banana seeds, this study used perceived seed shortage as a proxy for seed demand and highlighted the critical role of sociodemographic factors in shaping this demand. This provides insight into how different farmer groups experience seed demand based on their unique socioeconomic and demographic characteristics. It identifies the household size, income, and sex of the household head as predictors of farmers' banana seed demand. This highlights the influence of gender dynamics on banana seed acquisition behaviour and on determining the demand for seeds. These findings demonstrate that banana seed demand is influenced not only by the physical availability of seeds but also by the socio-demographic characteristics of farmers.

Improving banana seed systems—and, by extension, VPC seed systems—requires a comprehensive, multi-dimensional approach. Integrating the clustering approach into seed system design allows for more targeted interventions that address the diverse needs of different farmer groups, strengthen both formal and informal seed systems, and promote gender equity. By understanding seed demand through the lens of sociodemographic factors, more effective and sustainable seed distribution strategies can be developed, ultimately improving seed security across various contexts. This approach will help to create more equitable, resilient, and sustainable VPC seed systems that meet the needs of all farmers, regardless of their socioeconomic background.

## Study Limitations

Although insightful, this study is limited by its small sample size and focus on specific regions, which may constrain the generalisability of the findings. The cross-sectional design captures behaviours at a single point, overlooking temporal dynamics. Future research should expand the geographic scope, use longitudinal data to track changes over time, and integrate qualitative insights to deepen the understanding of sociocultural influences on seed demand and sourcing behaviour. Exploring digital solutions for seed distribution can also enhance seed-system interventions.

The socio-demographic clustering approach may fail to capture dynamic factors, such as evolving gender roles or individual preferences, which transform under shifting market trends (Elias et al., 2020). Farmers' preferences are also dynamic and may not consistently align with predefined clusters, suggesting the necessity for a more adaptable approach to comprehending farmer behaviour.

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