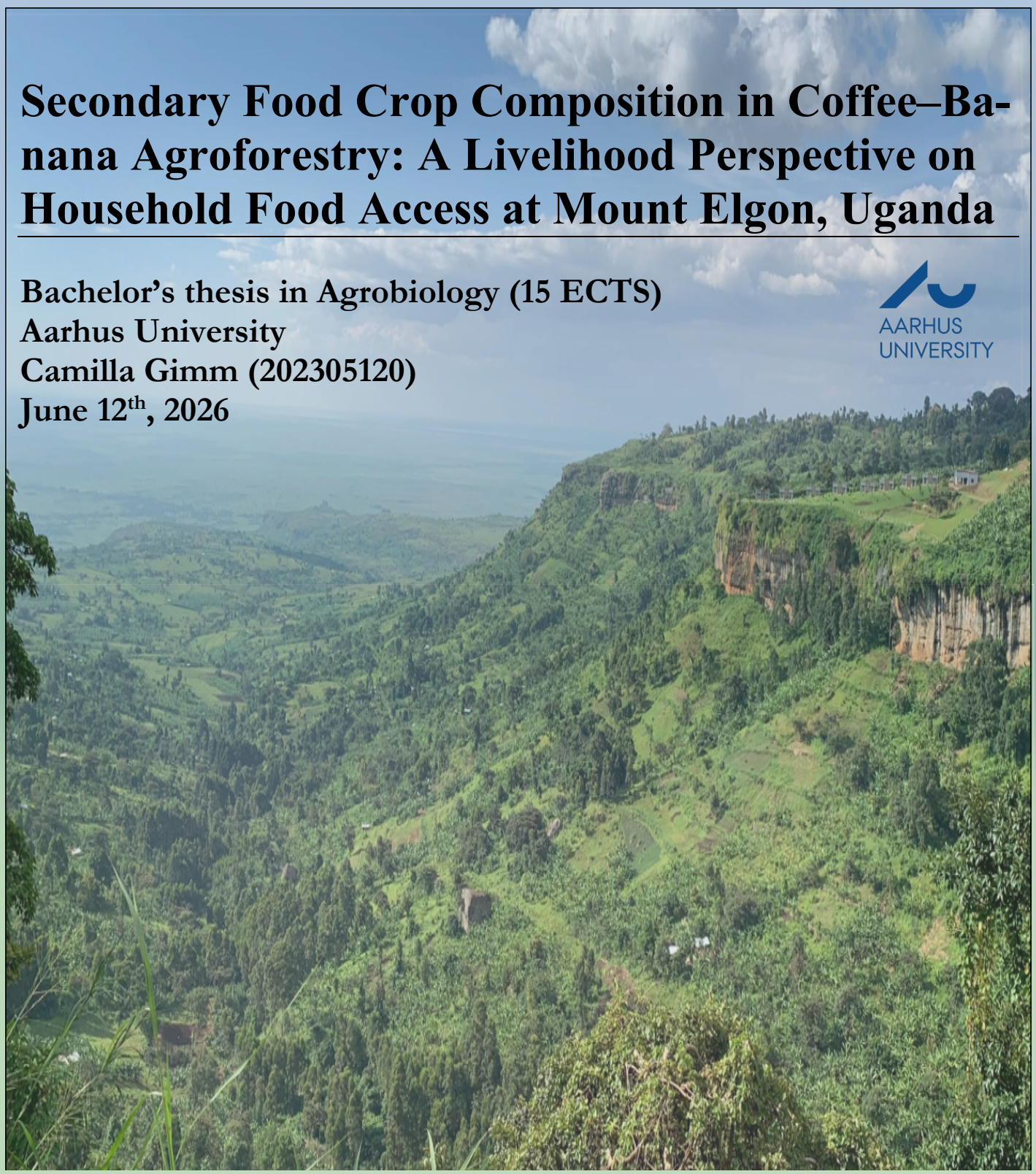
Secondary Food Crop Composition in Coffee–Banana Agroforestry: A Livelihood Perspective on Household Food Access at Mount Elgon, Uganda



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Camilla Gimm (202305120)
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Main supervisor: Anne Mette Lykke - Senior Researcher
Department of Ecoscience - Terrestrial Ecology

Co-supervisor: Torsten Rødel Berg - Senior Advisor
Department of Agroecology - Agricultural Systems and Sustainability

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Abstract (English)

In the Mount Elgon area of Uganda, a large proportion of farmers are engaged in coffee production in small-scale systems, mainly within coffee-banana agroforestry. Research primarily focuses on coffee as the main cash crop rather than on secondary food crops (crops cultivated alongside coffee for household food consumption). Yet these crops contribute to direct food access, reduce market dependence, and enhance system resilience through crop diversity.

Building on this context, this study examines how farmers' livelihood characteristics shape secondary food crop choices and discuss how these crops support direct food access and household self-sufficiency.

The study uses data from the AfPEC project, sampled in the sub-counties of Bushiyi, Sipi, Bufumbo, and Buginyanya. The data consist of quantitative livelihood variables such as age, gender, education level, sub-county, household size, number of gardens, and land area. Principal Coordinates Analysis (PCoA) and supporting figures are used to analyze variation in crop composition and its relationship with livelihood variables.

The analysis showed that households cultivate diverse secondary food crops, with bananas, maize, cassava, yams, and beans being the most widespread and important. Variation in crop composition was primarily explained by sub-county, which was the only significant livelihood variable, suggesting a strong influence of local agroecological and socioeconomic conditions, while other selected livelihood variables explained a limited proportion of the variation in crop composition.

These findings highlight the complexity of decision-making shaped by interconnected livelihood and contextual factors beyond those captured in this study. Strengthening direct food access may benefit from locally adapted advisory services, farmer-to-farmer knowledge exchange, nutritional crop assessments, and mixed-methods research that captures socio-cultural drivers of crop choice.

Abstract (Danish)

I Mount Elgon området i Uganda arbejder en stor del af landmændene med kaffeproduktion i småskalaproduktioner inden for kaffe-banan-skovlandbrug. Forskningen har primært fokuseret på kaffe som den centrale cash crop fremfor de sekundære fødevareafgrøder (De afgrøder, der dyrkes udover kaffen til direkte husholdningsforbrug). Disse afgrøder spiller ellers en vigtig rolle ved at sikre direkte adgang til fødevarer, mindske afhængigheden af markedskøb og styrke systemets robusthed gennem øget afgrødediversitet.

På baggrund af denne kontekst undersøger dette studie, hvordan landmænds levevilkår påvirker valget af sekundære fødevareafgrøder, samt diskutere hvordan disse afgrøder bidrager til husstandenes direkte fødevareadgang og selvforsyning.

Studiet anvender data fra AfPEC-projektet, indsamlet i følgende sub-counties: Bushiyi, Sipi, Bufumbo og Buginyanya. Data består af kvantitative levevilkårsvariabler herunder alder, køn, uddannelsesniveau, sub-county, husstandsstørrelse, antal haver og landareal. Der er anvendt Principal Coordinates Analysis (PCoA) samt supplerende figurer til at analysere variationen i afgrødesammensætningen og dens sammenhæng med levevilkårsvariablerne.

Resultaterne viste, at husstandene dyrkede en bred vifte af sekundære fødevareafgrøder, hvor bananer, majs, kassava, yams og bønner var de mest udbredte og betydningsfulde. Variationen i afgrødesammensætningen kunne primært forklares af sub-county, som var den eneste signifikante variabel. Dette pegede på, at lokale agroøkologiske og socioøkonomiske forhold havde en stor betydning, mens de øvrige undersøgte levevilkårsvariabler kun i begrænset omfang kunne forklare variationen.

Samlet set understreger resultaterne, hvor komplekse landmænds beslutninger er, og hvordan de påvirkes af en række sammenhængende levevilkårs- og kontekstuelle faktorer, som ikke fuldt ud er fanget i dette studie. Husstandenes direkte fødevareadgang kan med fordel styrkes af lokalt tilpasset rådgivning, vidensdeling mellem landmænd, ernæringsmæssig vurdering af de sekundære afgrøder samt mixed-method forskning, der kombinerer kvalitative og kvantitative forskningsmetoder, der bedre indfanger de socio-kulturelle drivkræfter bag valget af sekundære fødevareafgrøder.

Introduction

Agroforestry has been highlighted as an efficient and sustainable agricultural system that can enhance multiple ecosystem services, including improving soil structure, reducing the risk of erosion, protecting water resources, and increasing carbon storage, and biodiversity (Kuyah et al., 2019, Mathieu et al., 2025). At the same time, agroforestry can contribute to a more diversified and robust production system, as it allows for the cultivation of multiple crops and the harvest of various products, such as vegetables, fruits, coffee, nuts, and timber (Grass et al., 2020, Rice, 2008). This is particularly relevant in the context of climate change, as a diverse crop composition – in contrast to monocultures – enhances the resilience of the farming system. Thereby, it increases its capacity to cope with climate-related challenges and enhance food security (Altieri et al., 2015, Vernooy, 2022, Holt-Giménez, 2002).

Agroforestry is an especially important tool in the Mount Elgon area in Uganda, a unique highland landscape surrounding the extinct Mount Elgon volcano. The area is characterized by steep slopes, high altitudes, growing population, and increasing pressure on land resources. Combined with variability in weather events and more intense rainfalls due to climate change, these conditions contribute to soil erosion and frequent landslides, which is a risk to agricultural production and rural livelihoods (Jiang et al., 2014, Knapen et al., 2006, Sassen et al., 2013, Mugagga et al., 2012a, Mugagga et al., 2012b).

In Uganda, a large proportion of the population depends on smallholder agriculture (Jiang et al., 2014, van Asten et al., 2011), making productive and resilient farming systems crucial for both food security and income generation (Mugagga et al., 2012b, van Asten et al., 2011). Coffee production, in particular, is a major contributor to Uganda's national economy and is vital source of livelihoods for rural households as 42% of farming households engage its production (UCDA, 2021). Uganda ranks as the sixth largest coffee producer and exporter globally, exporting approximately 6,515,000 of 60 kg coffee in 2025, thereby making coffee one of the country's most revenue-generating crops (USDA, 2025). The sector is dominated by small-scale systems, as 90% of coffee is produced on farms smaller than three hectares (Gram et al., 2018).

Most coffee is grown in coffee–banana agroforestry systems in which banana trees provide shade for the coffee plants (van Asten et al., 2011). Besides the primary production of coffee, farmers cultivate secondary crops including annual crops such as maize, beans, and vegetables, alongside various tree species grown for purposes including fruit, timber, and fuelwood (Banana et al., 2014). Secondary crops broadly refer to all crops cultivated alongside coffee within agroforestry systems and they serve multiple

purposes, including food consumption, medicinal use, animal fodder, and income generation. However, this study focuses specifically on the secondary crops used for household food consumption, referred to as secondary food crops.

While coffee–banana agroforestry systems have been widely studied in relation to coffee productivity, ecosystem services, and climate resilience, research has primarily focused on coffee as the main cash crop rather than on the role of secondary food crops within these systems. Yet, secondary food crops contribute to household food access by providing direct sources of food and nutrition, reducing dependence on market purchases, and enhancing the resilience of agroforestry systems through increased crop diversity (Gram et al., 2018, van Asten et al., 2011). Existing studies have paid limited attention to how farmers' choices regarding secondary food crops influence household food security and self-sufficiency. This represents an important gap as household income is not exclusively allocated to food purchases but must also cover expenses such as school fees and medical bills (Jacobsen and Kroijer, 2024). This highlights the relevance of examining how secondary food crops contribute to household self-sufficiency and thereby shed light on food security through direct food access, as income from cash crops does not necessarily result in improved food security. Understanding what shapes farmers' decisions regarding secondary food crops is crucial for identifying constraints and opportunities for strengthening food security in Uganda, particularly in the Mount Elgon area.

This study seeks to understand how farmers' livelihood characteristics shapes the choice of secondary food crops in coffee-banana agroforestry systems at Mount Elgon and discusses how these secondary food crops may support direct food access and household self-sufficiency. This is done by identifying the cultivated secondary food crops, analyzing how livelihood related factors are related to farmers' secondary food crop composition, and analyzing how crop importance and crop diversity vary across households. In addition, the study seeks to identify potential strategies to enhance direct food access and food security based on the findings.

Theory

Food security

Coffee-banana agroforestry has the potential to contribute to local food security through a combination of income generation and the production of secondary food crops. Food security can be described from four dimension: availability, access, utilization, and stability (FAO, 2006).

Food supplies can be available through production or purchase while access is about whether the households have physical and economic resources to obtain available food to secure a nutritious diet (FAO, 2006, Alonso et al., 2018, Vink, 2012). Access to food can be obtained indirectly through the sale of goods, thereby generating income and securing economic access to food. Alternatively, food can be accessed through the cultivation of crops, which provides direct access to food for consumption (Peng and Berry, 2019, Vink, 2012). Utilization concerns the proper preparation and consumption of food, since achieving a healthy and nutritious diet depends not only on food availability and access, but also on how food is prepared and used (FAO, 2006, Alonso et al., 2018, Mugagga et al., 2012b). Access to clean water, sanitation, and health care improves both food utilization and subsequent nutritional and health outcomes (FAO, 2006). Stability refers to availability, access, and utilization being stable through time. Stability can be disrupted by economic or climatic crisis, seasonal food insecurity, wars, and conflicts (Vink, 2012, FAO, 2006). All four dimensions must be in place to achieve full food security (Peng and Berry, 2019).

In Uganda, physical and economic access is limited due to inadequate infrastructure and high prices (Ssennoga et al., 2019, Njuguna et al., 2024, Brenya and Zhu, 2023). In Uganda, 71% of the population are characterized as subsistence farmers, even if 50–60% of the food consumed in Ugandan households is purchased from the market (Brenya and Zhu, 2023) and the prices has more than doubled since 2010 (Ssennoga et al., 2019). Within coffee–banana agroforestry systems, coffee is primarily cultivated as a cash crop and sold to generate income, thereby enabling economic access to food, while bananas are both used a cash crop and for household consumption (Gram et al., 2018, van Asten et al., 2011). However, household income is rarely allocated exclusively to food purchases, as it must also cover school fees and medical costs (Jacobsen and Kroijer, 2024). This implies that income from cash crops does not automatically lead to improved food security. Consequently, the role of secondary food crops becomes relevant to investigate, as they may contribute to household self-sufficiency by providing direct food access.

Livelihood perspectives

The definitions and the livelihood framework used in this section are based on DFID (2001). The livelihood perspective provides a framework for development that places farming households at the center of analysis, rather than focusing solely on production systems, markets, and resources (DFID, 2001). This holistic approach recognizes that farmers operate within complex and dynamic contexts characterized by vulnerability and change caused by external forces where they continuously must mobilize their

assets. The farmers' assets refer to the conditions and resources available to them, which farmers use in different ways depending on the circumstances. The environment in which they operate is referred to as the vulnerability context, which encompasses shocks, trends, and seasonal changes that shape livelihood strategies and outcomes.

Within this framework, acknowledging the vulnerability context is essential, as it can directly affect livelihood assets and influence farmers' strategies. Shocks such as natural events (e.g. floods and storms), economic fluctuations (e.g. rapid changes in exchange rates and terms of trade), and human health crises can directly affect the farmers' assets. Trends such as population growth, resource availability, technological development, and economic changes are more predictable but still influence the productivity and efficiency. Seasonality also affects livelihood strategies and outcomes through changes in prices, production levels, health, and employment opportunities. Not all these factors are negative, but the vulnerability context recognizes that many of these events create stress and have a negative impact on the most vulnerable and poorest populations.

Within the livelihood framework, there are five categories of livelihood assets: human capital, social capital, natural capital, physical capital, and financial capital. These assets constitute the foundation for securing livelihoods. Multiple factors influence farmers' decision-making, but decisions are made within a context, and the livelihood perspective creates a framework to investigate how these 5 capitals influence livelihood outcomes and decision-making.

In this study, the livelihood perspective is applied to provide an analytical framework for understanding how farmers' decisions are shaped by the assets available to them. A sustainable livelihood is resilient, as it can recover from shocks and maintain its assets over time without compromising the livelihoods of others or degrading natural resources. This perspective is particularly relevant in the context of climate change, where increasing environmental variability poses significant risks to food security in vulnerable areas such as Mount Elgon. Investigating cropping patterns through a livelihood lens allows for a deeper understanding of how farmers adapt their strategies to secure food for their households under changing conditions.

The analysis focuses particularly on human and natural capital, as they are most relevant to this study. However, all five livelihood capitals are introduced in this section to provide a comprehensive understanding. The capitals are interconnected, and strengthening one capital can have positive effects on

others, ultimately improving livelihood outcomes. However, these interactions are often complex and difficult to measure, which makes a holistic perspective essential when analyzing farmers' decision-making.

Human capital refers to the farmers' knowledge, skills, health, and ability to work and is particularly important as it is necessary to make use of the other forms of capital. The amount and quality of labor a farmer can provide to ensure their livelihood depends for example on their skill and health level. Overcoming sickness and improving education are seen as main livelihood goals as it is the key to overcome poverty (DFID, 2001). Farmers can invest directly in their human capital by attending school and taking care of their health. The households at Mount Elgon invest a large proportion of their income in education to increase their human capital (Jacobsen and Kroijer, 2024). However, when access to education or healthcare is constrained by structural or cultural factors, improvements in human capital require indirect effort by changing these constraints through policy measures or by challenging social norms, such as those limiting girls' access to education.

The most effective way to support human capital is to combine both direct and indirect approaches, as it gives access to education and health care while addressing the barriers such as gender roles or policy. By strengthening other capitals, such as financial capital, human capital can be indirectly enhanced, for example by enabling households to afford education for their children. Strengthening physical capital by installing water and energy systems that reduce time on non-productive activities like collecting fuel wood and water, can help free up time for education. Specialized education can be effective, but it is crucial that the knowledge is accessible and relevant for the local conditions. The role of specialized education as a livelihood strategy will be elaborated in the section on *Diversified rural livelihoods*.

Natural capital refers to the natural resources that people use to sustain their livelihoods. It includes tangible resources such as land and trees, as well as intangible public goods such as the atmosphere and biodiversity. Ecosystem services such as erosion protection and nutrient cycling are also a part of this capital. In the context of this study, natural capital forms the basis for agroforestry and the cultivation of secondary food crops and is the foundation for food production.

There is especially a connection between natural capital and the vulnerability context, as shocks can damage or destroy natural capital, for example when heavy rainfall leads to erosion and floods in vulnerable areas. Seasonal changes also affect the availability and productivity of natural capital. Natural

capital is particularly important for the local people of Mount Elgon, because a large proportion of the population relies on small-scale farming and is therefore dependent on natural resources and ecosystem services for their livelihoods and food security. When natural capital is damaged, food production declines, which can lead to poor nutrition and ultimately undermine human capital, particularly health. In addition, natural capital influences air quality and drinking water, thereby affecting human health.

Natural capital can be strengthened indirectly through the conservation and enhancement of natural resources and ecosystem services through environmental policies and legislation. This can also be supported by improvements in the institutions, organizations, and governance structures involved in natural resource management as these structures play a crucial role in determining how natural resources are utilized. Natural capital can also be directly strengthened through the conservation, enhancement, and protection of natural areas, resources, and biodiversity.

Physical capital refers to the physical assets that people use to support their livelihoods, such as infrastructure and equipment. These assets can increase productivity and efficiency in agriculture and improve access to services and resources. Weak physical capital constrains the development of human capital by increasing time spent on essential but non-productive activities and limiting time and access for education and healthcare. In addition, inadequate equipment and infrastructure reduce productivity and income, thereby restricting households' ability to invest in health and education.

Social capital is a broad and context-dependent term, but in the case of the livelihood framework, it refers to the social network farmers use to support their livelihood. Being a member of a cooperative is an opportunity to increase social capital. Social capital can transform structures and processes and extend the farmers access to other resources, as trust facilitates collaboration, increases safety nets and reduces costs. Hereby, an increase in social capital can lead to an increase in financial capital. There is also a strong connection between social and human capital, as social networks enable sharing of knowledge, development, and innovation. A strong social capital can also positively influence physical and natural capital by working together to maintain shared infrastructure and manage common natural resources.

Financial capital is the financial resources that the farmer has access to support their livelihood and is important because it provides the household with access to other resources such as food, education, and equipment. Strong financial capital can enhance a household's influence in the local community

through participation in organizations and politics, though it can both have positive and negative effects depending on how it is used. Social capital can influence financial capital as social relations build trust, strengthen cooperation, and expand networks and relationships, which can improve access to group-based lending, increase opportunities to obtain loans, and create better access to jobs. However, strong financial capital does not necessarily translate into effective use of financial resources, as structural constraints and system limitations, as well as low levels of human capital in terms of education and knowledge, may hinder a productive allocation of these resources.

The way in which farmers combine and utilize these capitals to achieve their goals is described as livelihood strategies. One way of addressing the vulnerability context is to support local farmers in becoming more resilient to external shocks and stress. This can be achieved by supporting farmers in building up their assets. However, this requires an understanding of local livelihoods and the strategies that underlie them to identify the factors that constrain farmers from achieving their objectives. These strategies are dynamic and continuously adapted in response to changing opportunities and constraints. In this study, the choice of secondary food crops is understood as part of farmers' livelihood strategies, where the intended outcome is to enhance food security.

Due to data limitations, it is not possible to include all aspects of the livelihood framework in the analysis. Ideally, all five capitals would be examined to fully understand their influence on farmers' decision-making regarding secondary food crops. However, this study primarily focuses on human and natural capital and its relationship with cropping patterns, while acknowledging that other forms of capital also play an important role.

Diversified rural livelihoods

A diversified rural livelihood is a way in which households combine different activities and social support networks to survive and achieve a better quality of life (Ellis, 1998). It is a process where households maintain and continuously adjust their activities to changing circumstances over time (Ellis, 2000). A diversified livelihood relies on more than just diversified income generation through sales of crops, livestock, wages, and remittances (Ellis, 1998). It is also about access to social support networks, as well as access to resources and the ability to withstand crises (Butler and Mazur, 2007, Ellis, 1999). These resources can be understood through the five livelihood capitals (Ellis, 1999), as explained in the previous section. A diversified rural livelihood contributes to sustainability by enhancing resilience to

shocks, stress, and uncertainty by reducing dependence on any single livelihood activity, spreading risks, and making effective use of human, social, physical, natural, and financial capital (Ellis, 1999).

Several studies have found that education, both within and outside the agricultural sector, is a key factor contributing to livelihood diversification (Ellis, 1998, Dercon and Krishnan, 1996, Evans and Ngau, 1991). Low levels of education are closely associated with poverty; therefore, human capital plays a crucial role in livelihood diversification, as education enables individuals to specialize and thereby contribute to greater diversification at the household level (Ellis, 1999, Ellis, 1998). Within the agricultural sector, more educated farmers tend to adopt more climate-change adaptation practices (Ali and Erenstein, 2017, Twecan et al., 2022). Education may therefore contribute to livelihood diversification both by improving agricultural practices and by creating opportunities beyond the agricultural sector. The prioritization of children's education outside the agricultural sector also reflects a diversified livelihood strategy. When children gain employment outside rural areas and the agricultural sector as a result of their parents' investment in education, they send a part of their income back to the household in form of remittances to support and invest in the household's livelihood (Ellis, 1998, Ellis, 1999). These remittances can function as a safety net because their income is not correlated with the agricultural risks (Ellis, 1998, Ellis, 1999).

Livelihood diversification is also closely related to natural capital. When natural resources are affected by shocks like drought and floods, this can act as a push factor towards diversification, motivating the household to engage in additional livelihood activities both on and off the farm (Ellis, 2000, Evans and Ngau, 1991). On the other hand, livelihood diversification can also act as a preventive strategy. Income generated from diversified livelihood activities can be reinvested in environmental recovery, sustainability, and innovation, thereby protecting and enhancing natural capital (Ellis, 1999, Ellis, 1998). An increase in natural capital, such as better soil quality and greater land availability, can also lead to an increase in livelihood diversification, as it opens opportunities for innovation and adaptation strategies (Ali and Erenstein, 2017). When high agricultural productivity derived from strong natural capital generates higher income, households can reinvest these resources in education, new technologies, and improved farming practices. Such investments can strengthen their capacity to adapt to climate change and diversify their livelihoods (Ali and Erenstein, 2017, Ellis, 1998, DFID, 2001). The increased productivity can also release labor to other activities off-farm and thereby increase the household livelihood diversification (Ellis, 1998, Antonelli et al., 2022).

Materials and methods

AfPEC project

This study is based on baseline data from the AfPEC project led by Aarhus University, conducted in the Mount Elgon region of Uganda over a five-year period from April 1st, 2024, to March 31st, 2029 (AfPEC). The objective of the AfPEC project is to investigate agroforestry as a tool to address climate change and biodiversity loss. This is done by documenting the effects of agroforestry on ecosystems services and livelihood benefits while collaborating with local farmers around Mount Elgon to support sustainable coffee agroforestry practices. The AfPEC project also involves determining the most suitable tree species and best practices, as well as understanding the factors that motivate coffee farmers to engage in agroforestry. To evaluate the livelihood benefits of agroforestry, it is relevant to understand how agroforestry influences food security at a household level. Agroforestry increases crop and income diversification, ensuring that farmers are not solely dependent on coffee as their main source of income to purchase food, pay for medical expenses, and cover school fees etc. Agroforestry also allows households to produce food directly for household consumption. Consequently, this study focuses on the composition of secondary food crops to assess how agroforestry contributes to direct food access and food utilization at the household level.

Study area description

The research for the AfPEC project took place in the unique highland surrounding the 4321 m high extinct volcano, Mount Elgon, in eastern Uganda (Jiang et al., 2014), covering the coffee-growing sub-counties of Bushiyi, Sipi, Bufumbo, and Buginyanya (Fig. 1). The average altitude of the sub-counties is respectively 1590 m, 1890 m, 1346 m, and 1812 m (Willemoes, 2025), reflecting the unusually elevated terrain that characterizes the Mount Elgon region and shapes its distinctive agroecological conditions.

The Mount Elgon region is characterized by tropical montane climate, fertile volcanic soils, and steep slopes (Sassen et al., 2013, Knapen et al., 2006). The average slope of Mount Elgon is around 4° however the sub-counties of Bushiyi, Sipi, Bufumbo, and Buginyanya are approximately 16°, 12°, 11°, and 13° (Willemoes, 2025). There are two main rainy seasons per year, occurring in March-May and September-November (Knapen et al., 2006, Sassen et al., 2013), and the annual precipitation ranges from 1500-2200 mm, while the mean temperature varies between 15-23°C (Mugagga et al., 2012b).

The fertile soils in Mount Elgon has supported coffee production since 1912 (Sassen et al., 2013). It is most common that Arabica coffee is cultivated in the banana-coffee agroforestry systems, together with different shade trees and annual crops such as maize, beans, vegetables (Sassen et al., 2013).

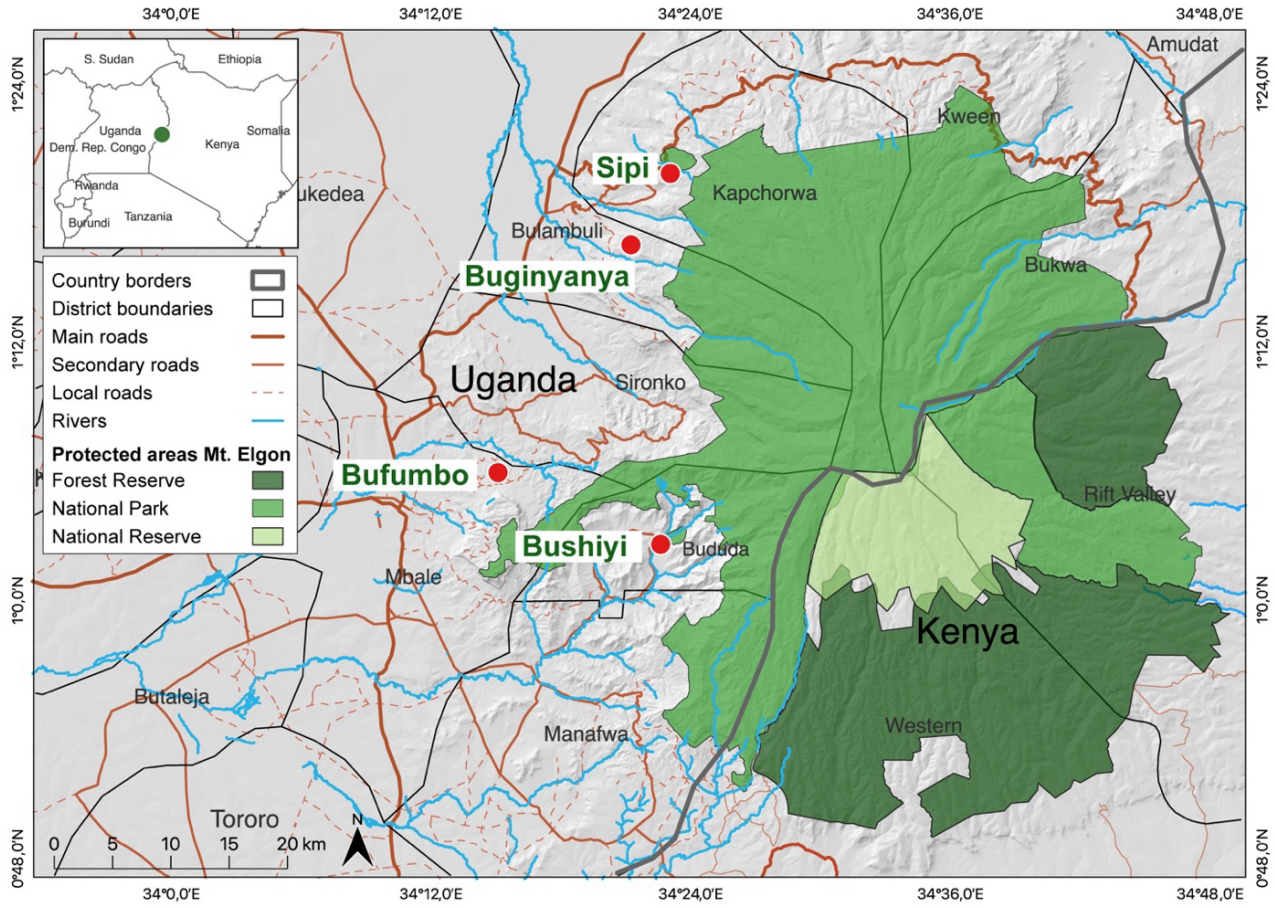

Fig. 1: Map of AfPEC project area and the four study sites: Bushiyi, Sipi, Bufumbo, and Buginyanya (Willemoes, 2025)

Sampling

The data includes quantitative data collected from the sub-counties of Bushiyi, Sipi, Bufumbo, and Buginyanya and is stored in Excel. Interviewers collected information from 97 randomly selected households under the AfPEC project through interviews using questionnaire tools with one informant per household.

For the present study, only data on secondary food crops and selected relevant variables elaborated in the *Livelihood variables* section were used for further analysis. One household was not listed as cultivating any secondary food crops and was therefore removed to avoid issues caused by a row of zeros in the analysis.

Data collection

Data was collected by project staff including members of Seniors Without Borders, master's students from Aarhus University, and members of the Youth League for Environmental Change. The baseline data included socio-economic data collected through questionnaires and interviews on farmers' livelihoods, economic conditions, workload, family structure, and more. In addition, the interviewers collected information on farmers' assets and their management practices, including information about the crops cultivated by each household and their respective uses such as medicine, animal fodder, income generation, and food consumption.

Livelihood variables

Information on secondary food crops was included for data analysis together with the most relevant variables, to minimize the risk of identifying spurious correlations, including the informant's household head's age and gender, sub-county, number of children living in the household, education level of the household head, number of gardens, and land area. In this study, variables such as age, gender, education, and children living at home are used as indicators of human capital, while number of gardens and land area are used as indicators of natural capital, as these were the relevant variables available in the dataset. One household was recorded as having zero gardens due to a data entry error. However, this value was adjusted to one garden in the dataset, although the actual number of gardens may be higher.

Only information on secondary food crops was included in the analysis together with the previously mentioned variables. The informants ranked the secondary food crops from least important (1) to most important (5), while a value of 0 indicated that the crop is not cultivated in the household. When a crop value was missing due to data recording errors by the interviewer, a value of 0.5 was assigned in the new dataset to distinguish them from non-cultivated crops while placing them at the lowest importance score. This approach ensures that the crops are not overestimated and minimizes the risk of affecting the overall distribution of importance scores and the comparability between crops assigned valid importance scores ranging from 1 to 5.

Secondary food crops

A wide variety of secondary food crops are grown in coffee agroforestry systems (appendix 1), with banana being the most common. There are many varieties of bananas which include matooke (often referred to as bananas) and sweet bananas. For simplicity these are grouped under one category as "bananas". Beans are usually the red mottled beans which are different from the category soybeans, while

Irish potatoes are categorized simply as "potatoes".

Secondary food crops mentioned less than three times across all informants have been combined into one category as "rare" crops. This includes vanilla, ginger, carrots, black nightshade, sesame seeds, sunflower, cow peas, wheat, millet, sorghum, cocoa, rosemary, pineapple, basil, okra, elephant grass, and green pepper.

Data analysis

This study utilizes baseline data from the AfPEC project in an explorative manner. Principal Coordinates Analysis (PCoA) was conducted to visualize similarities among informants. To identify which crops contributed most to the observed patterns, crop vectors were fitted onto the ordination space. Similarly, livelihood variables were fitted as vectors to examine their association with the ordination. These vectors indicate the direction and strength of each crop or livelihood variable, helping to interpret how crop choices vary among informants and how they might be influenced by the livelihood variables.

The Bray-Curtis distance measure was used to construct the distance matrix for the PCoA. Eigenvalues were extracted and converted to percentages to determine how much variation each axis explained, and the first two axes (PCoA1 and PCoA2), which explained the largest proportion of the total variation, were used for further analysis.

The relationship between PCoA scores (coordinates of informants in the ordination space) and numeric livelihood variables (I_age = age of informant, H_age = age of household head, Land area = size of land area in acres, No. children = number of children living home) was explored with 999 permutations to test significance.

The four sub-counties were assigned as colors and education level as symbols in the PCoA plot. Only 12 significant secondary food crops are visualized on the PCoA plot ($p < 0.005$). Data analysis was performed using RStudio version 2024.12.0 + 467 running R version 4.4.2.

Results

Descriptive overview of household characteristics

Data from 96 households across four sub-counties were used in this study (Table 1). 94.8% of the household heads were men and 5.2% were females. The number of households included in each sub-county ranged from 20-30 with the lowest representation in Bufumbo and the highest representation in Bushiyi.

Table 1. Gender distribution of the household heads across the four sub-counties: Bushiyi, Sipi, Bufumbo, and Buginyanya

Gender distribution by sub-county			
	Males	**Female**	**Total**
Bushiyi	28	2	30
Sipi	20	2	22
Bufumbo	20	0	20
Buginyanya	23	1	24

There was a substantial variation in household livelihood characteristics (Table 2). The age of household heads ranged from 28-83 years with a mean of 52 years. On average, households had 5.1 children living at home, ranging from 0-20, and 4.6 gardens, ranging from 1-30. Land area varied from 0.50-15 acres with a mean of 3.4 acres.

Table 2. Summary statistics of livelihood variables at household level (Age of household head, number of children living at home, number of gardens and land area in acres) including minimum, maximum and mean values

Summary of household livelihood variables				
	Age	**Children living home**	**Number of gardens**	**Land area**
Min	28	0	1	0.50
Max	83	20	30	15
Mean	52	5.1	4.6	3.4

Regarding general education, all three education levels (primary, secondary, and higher education) were represented in the four sub-counties (Fig. 2). Most of the household heads only had a primary education ranging from 32-55% in the four sub-counties with an average value of 48% (Appendix 2). However, a substantial amount also had completed secondary education ranging from 29-41% with an average value of 36% across the four sub-counties. Higher education was the least common educational level, accounting for 5-27% with an average value of 16%.

The most educated sub-county was Sipi with the highest share of higher education (27%), as well as the highest share of secondary education (41%). On the other hand, Bufumbo was the least educated sub-county, as it had the lowest share of completed higher education (5%), as well as the highest share of completed primary education (55%). Bushiyi and Buginyanya had a similar education distribution across the three educations levels with primary education being the most prevalent education accounting for 50% in Bushiyi and 54% in Buginyanya. This was followed by secondary education at 33% and 29%, respectively, and higher education at 17% in both sub-counties.

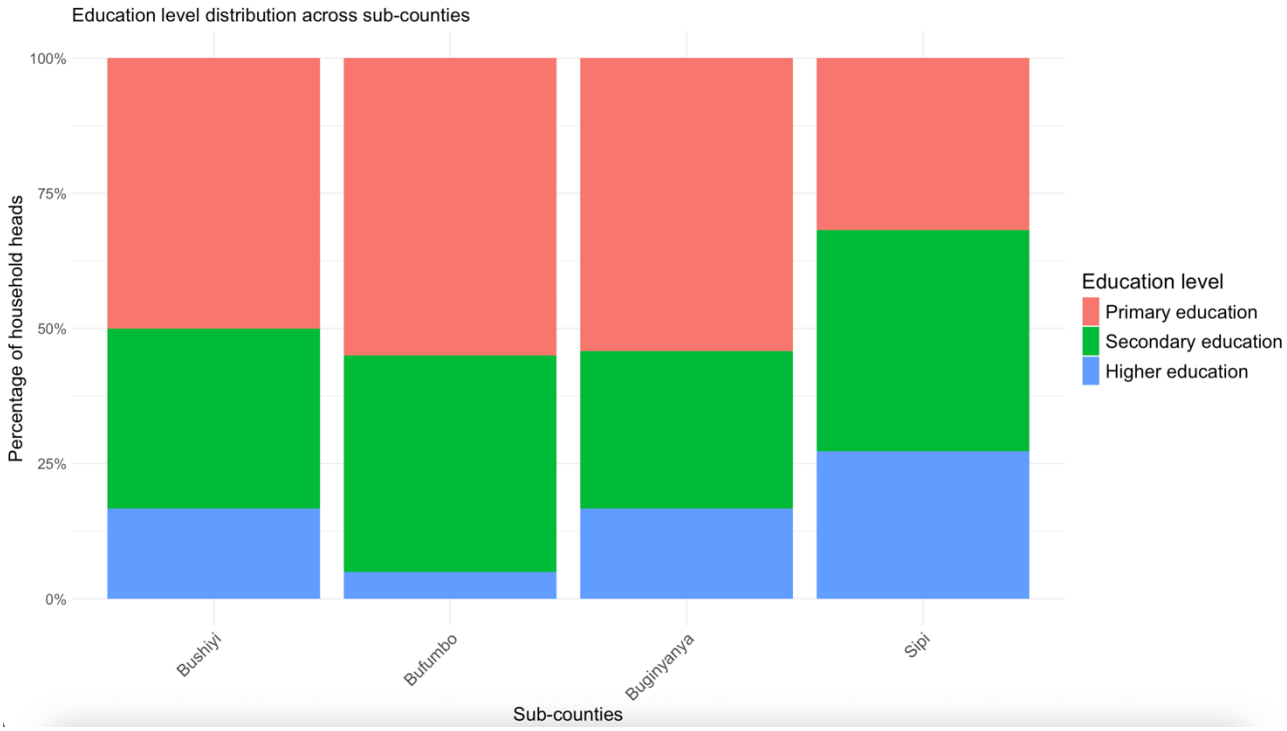

Fig. 2. Education level distribution across sub-counties. The four sub-counties are listed on the x-axis, while the y-axis illustrates the percentage of each education level for household head. The colors illustrate the education level (red = primary education, green = secondary education, blue = higher education).

PCoA and secondary food crop composition

The PCoA provided an overview of variation in crop composition among households (Fig. 3). A total of 61.8% of the crop variation was explained by the analysis with PCoA1 and PCoA2 accounting for 40.6% and 21.2%, respectively. Bananas, beans, maize, yams, cassava, and pumpkins were the main drivers of the observed differences among households. Onions, potatoes, sugar cane, chili, sweet potatoes, and ground nuts also contributed substantially to the observed crop variation.

Overall, three major crop groups emerged, each consisting of crops that tended to be prioritized together. These crop groups included (1) bananas, cassava, yams, and sweet potatoes, (2) bananas, potatoes, maize, beans, and onions, and lastly (3) groundnuts, chili, sugar cane, pumpkins, and sweet potatoes. Although three main crop groups were identified, each group encompassed many households that differed in the importance they assigned to individual crops. This demonstrates a gradient within each crop group, reflecting variation in household preferences and cropping strategies rather than distinct and uniform crop groups. Nevertheless, the results showed that households from the different sub-counties differ in their relative crop composition as households in Bushiyi tended to prioritize group (1). Sipi and Buginyanya placed greater emphasis on group (2), while households in Bufumbo tended to place greater importance on the crops belonging to group (3).

Sub-county was the only significant livelihood variable ($p<0.001$) explaining 25.32% of the variation in the crop composition, while there was no apparent pattern in education level. The age of the household head and the age of the informant, together with land area, number of gardens, and number of children living at home, explained only a limited proportion of the variation in crop composition. However, these livelihood variables could still help illustrate a trend and correlation among each other as seen in the strong correlation between age of informant and age of household head. This is likely because the informant and household were often the same person in the interviews. In addition, number of gardens and land area were also positively correlated with each other, and both variables showed a positive correlation with age of household head. This indicates that households with larger land areas tended to have more gardens, and that both larger land areas and a higher number of gardens were more common among households with older household heads.

Land area was positively correlated with crop group (1), suggesting that households with larger land areas tended to assign higher importance scores to these crops. Multiple livelihood variables were

positively correlated with crops from different crop groups, further supporting that households vary along a gradient in their cropping patterns rather than belonging to discrete crop groups.

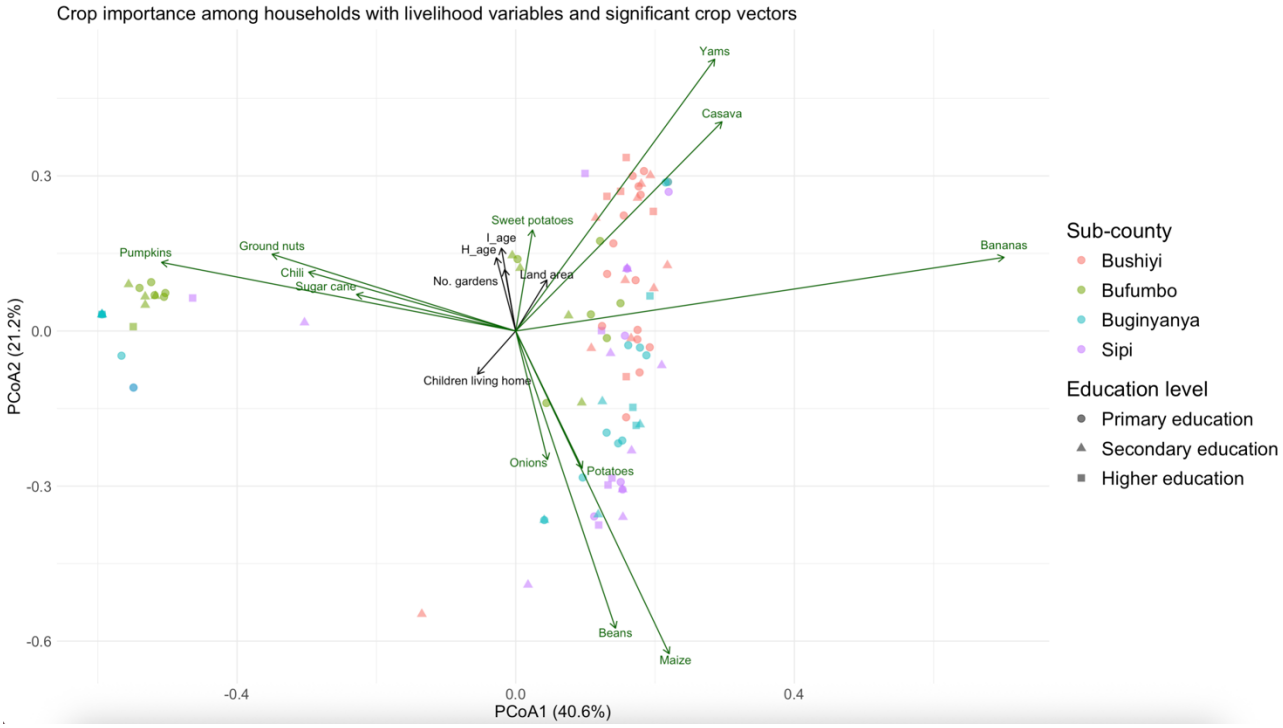

Fig. 3: Visualization of crop similarities among informants expressed in PCoA plot. Crop importance is reported by 96 informants from four sub-counties categorized by color (Bushiyi, Bufumbo, Buginyanya, and Sipi) and by education level of the household head categorized by symbols (Primary education, secondary education, and higher education). PCoA1 explained the largest proportion of variation (40,6%), while PCoA2 explained the second largest proportion of variation. Black and green vectors represent the strength and direction of the livelihood variables and significant crops, respectively.

Farmers highlighted several species as especially important (Fig. 4). Some key crops were both frequently mentioned, while also being highly ranked in importance. Bananas was the most mentioned and most important crop with 91 citations and an average importance of 3.8 followed by maize, cassava, yams, and beans each cited 56-68 times receiving average importance rankings of 2.0-2.8 (appendix 3). Some crops were less frequently mentioned but received relatively high importance scores such as onions, rare crops, and rice cited 5-13 times with a relatively high importance of 1.2-1.5. While more frequently mentioned crops with lower importance scores were sweet potatoes, cabbage, tomatoes, pumpkins cited 15-28 times with an average importance of 0.5-1.0 (appendix 3).

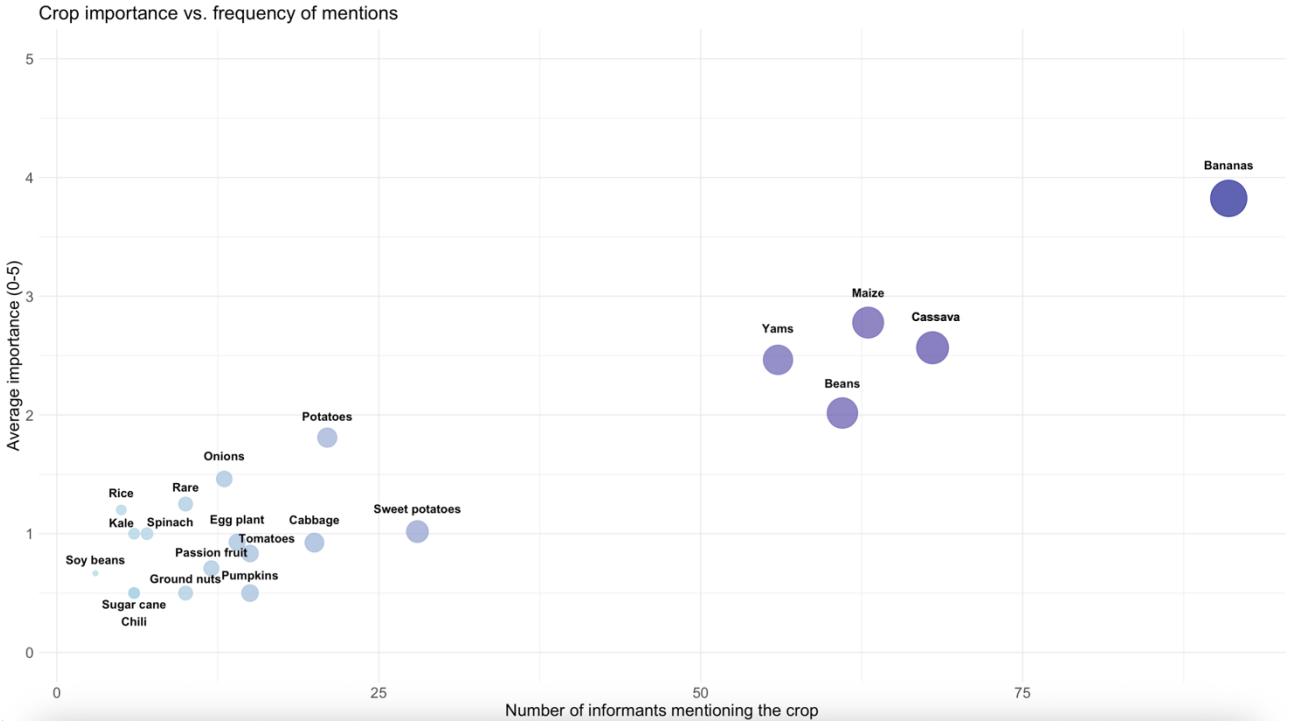

Fig. 4: Average crop importance and frequency of mentions. Y-axis shows the average importance (0-5, 5= most important), while the x-axis shows the number of mentions. The color and size of each bubble help visualize the importance of each crop by illustrating how many times the crop has been mentioned (many mentions = big and dark blue).

Bananas were an important crop, not only overall but across all four sub-counties with especially high importance scores in Bushiyi and Sipi (Fig. 5). Although yams, maize, cassava, and beans were important across all sub-counties, their prominence differed, with yams and cassava being particularly important in Bushiyi, maize in Sipi, and beans in Buginyanya. Although many species were cultivated, only a relatively small proportion showed high crop importance. Buginyanya had several crops that received no mentions, whereas Bufumbo and Bushiyi showed broader crop representation with most crops presented, although often with some low importance scores.

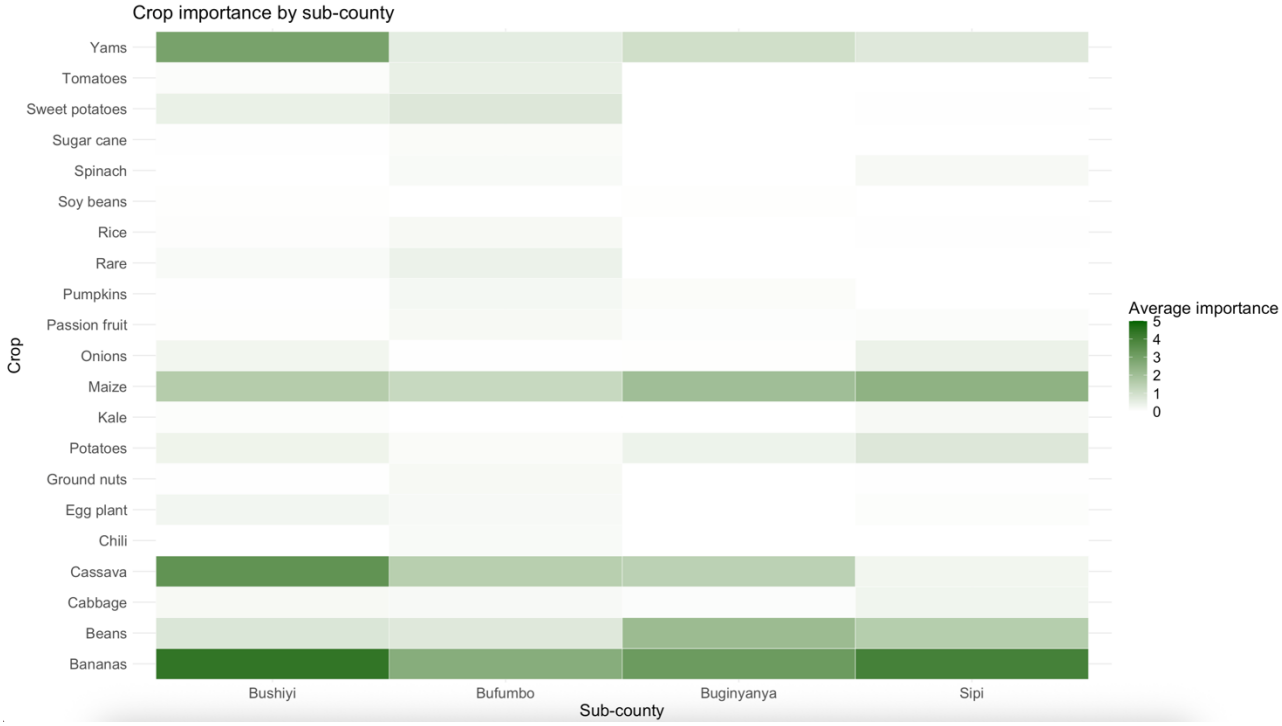

Fig. 5: Average crop importance by sub-county. The y-axis illustrates the crop species, while the x-axis illustrates the sub-counties. Bars are colored to illustrate the average importance of the sub-counties with a graduate green color scale from 0-5, with 5 being the most important crop. Darker green illustrates more important crops, while lighter colors being less important crops. White color means that the crop has not been mentioned in the sub-county.

Though bananas were overall the crop that had been mentioned the most, it was only the most mentioned crop in Bushiyi and Sipi (Fig. 6). Whereas cassava was the most mentioned crop in Bufumbo, and bananas and beans were the most mentioned in Buginyanya. Fewer crops were cultivated in Buginyanya with only 11 crops represented, while the three other sub-counties each cultivated between 15-19 different crops. In Buginyanya, no crops were cultivated that were not also grown in at least one other sub-county, while Bushiyi and Bufumbo stood out with cultivation of rare crops.

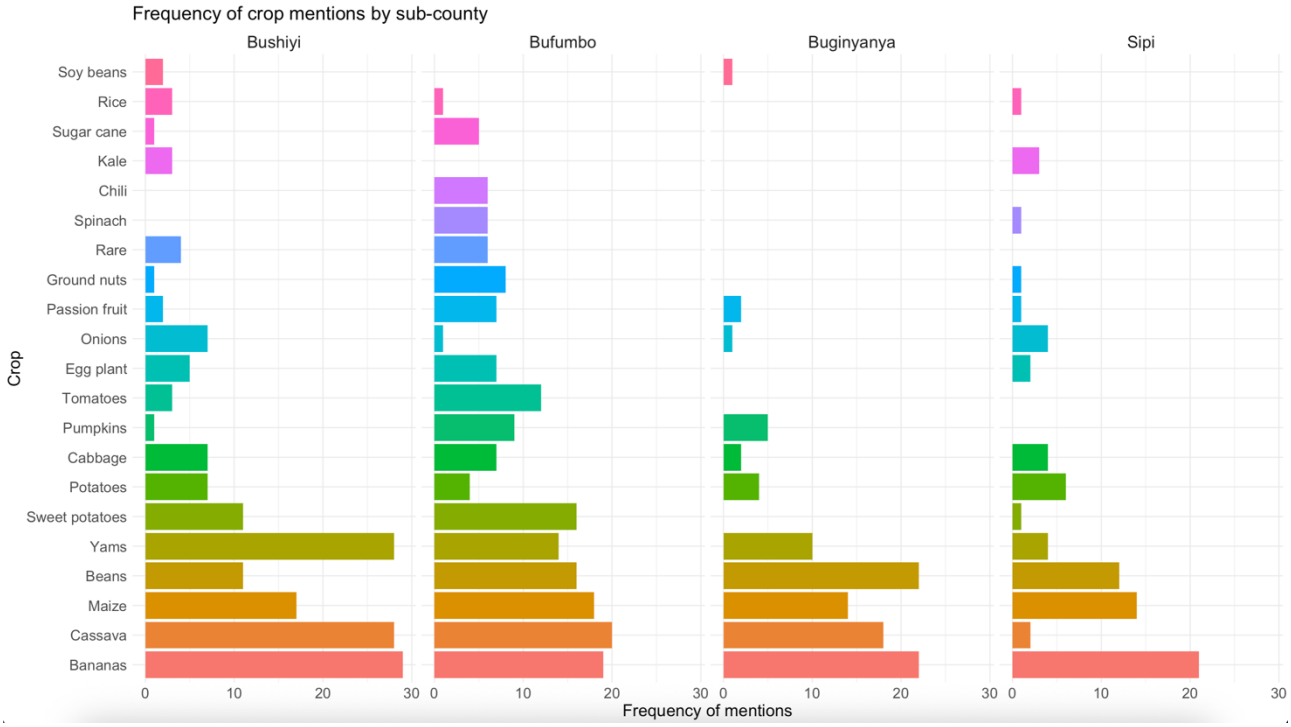

Fig 6. Frequency of crop mentions across sub-counties. The x-axis illustrates the frequency of mentions, while the y-axis shows the crops. Rainbow color scale for bars is used to provide a clear overview and facilitate comparison.

Beans, onions, and cabbage were the most important crops for male household heads compared to female household heads, with beans clearly being the most dominant crop (Fig. 7). Yams, eggplant, maize, and bananas were the most important crops for female household heads than among male household heads, with yams being the most dominant crop. Potatoes were similarly important for both genders as well as soybeans, chili, and sugar cane, however with a slightly higher importance score for the males. Fewer crops were considered more important for the females than crops for males, but these crops received higher importance scores than the crops rated higher by males.

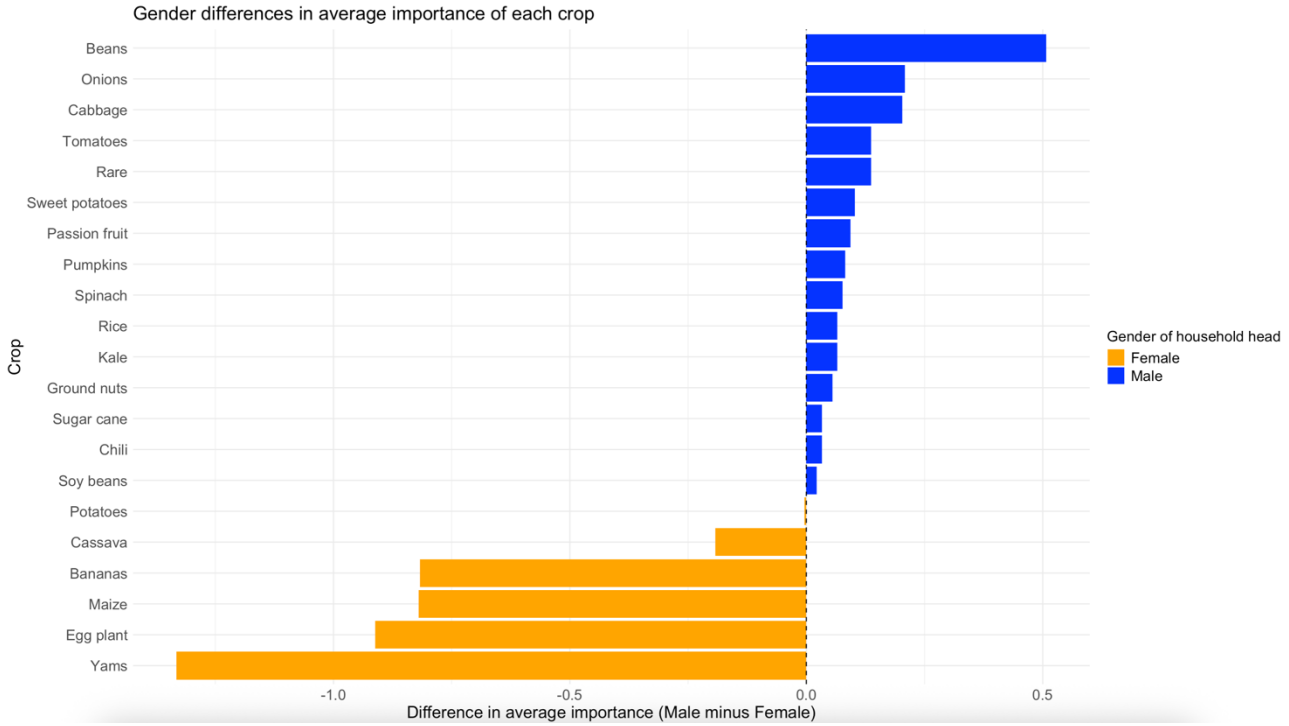

Fig. 7. Difference in average crop importance between female (n=5) and male (n=91) household heads. The crops are listed on the y-axis, while the difference in average importance is rated on the x-axis. For each crop, the average importance score (0–5) was calculated separately for men and women, and the difference was calculated as *(male − female)*. Positive values (blue bars) indicate that a crop is rated as more important by men on average, while negative values (orange bars) indicate higher importance among women. Values equal or close to zero reveal similar preference for the species between genders.

Discussion

The results are discussed in relation to covered theory, existing literature, and findings from other studies to provide a broader understanding of the results.

Crop choice and food security

The households generally cultivated multiple secondary food crops, although crop composition and crop importance varied across households. This variation reflects that households adopt different cropping strategies. Secondary food crop diversification within agroforestry has the potential to reduce dependence on market purchases and enhance the resilience of agroforestry systems by spreading production risks across multiple crops (van Asten et al., 2011). It may also improve soil quality and support other agroecological functions such as nutrient cycling, biodiversity, and natural pest regulation, ultimately contributing to improved household food security (Quandt et al., 2023, van Asten et al., 2011,

Gram et al., 2018).

Although households cultivated a diverse range of secondary food crops, some crops dominated. The results showed that bananas, maize, cassava, yams, and beans were both widely cultivated and ranked as highly important by households (Fig. 4). Similar patterns have been reported in previous studies, which highlight that certain crops, particularly bananas, beans, and maize, are deeply integrated into local agroforestry systems and often function as key staples in rural livelihoods (Sassen et al., 2013, Rahn et al., 2018, van Asten et al., 2011). These crops in the present study therefore may represent key staple crops within household livelihood strategies.

The importance of these crops may also be explained by their functional flexibility. Bananas are cultivated as both a cash crop and subsistence crop depending on market demands (van Asten et al., 2011, Sassen et al., 2013), suggesting that secondary food crops are not only used for household consumption but may also serve flexible functions influenced by market conditions. The prominence of bananas, maize, cassava, yams, and beans may then be linked to their functional flexibility, as they can function both as market-oriented cash crops and as subsistence crops for household consumption. From a livelihood perspective, this reflects how farmers combine different strategies to strengthen food security and reduce vulnerability. Income from cash crops contributes to financial capital, while cultivation of crops for household consumption supports direct food access. By diversifying crop production and adjusting the use of the crops between cash and subsistence functions, farmers can spread risk across multiple crops and functions (Antonelli et al., 2022, Vernooy, 2022).

Crop diversification and functional flexibility of crops together enhance agroecological and socio-economic resilience, as losses or reduced yields in one crop can be compensated by gains in others within the system, thereby reducing the impact of climate change on agricultural production and household food security (Vernooy, 2022). This highlights how diversified farming systems provide an important buffering capacity against environmental variability and economic uncertainty. The findings support Ellis' (1999, 2000) understanding of diversified livelihoods as dynamic and adaptive strategies, in which households continuously adjust the use of available resources in response to changing conditions, while spreading risk across multiple crops and livelihood functions. Overall, this contributes to enhanced resilience and reduced vulnerability to both environmental and economic shocks.

Crop choice and culture

Bananas were the most important crop across all sub-counties, while maize, cassava, yams, and beans also played key roles but varied in importance between sub-counties (Fig. 5). Crop diversity was lowest in Buginyanya and highest in Bushiyi and Bufumbo, where a wider range of crops, including some rare species, were cultivated (Fig. 6). Although households cultivated a diverse range of crops as several species were cultivated, production was concentrated around a limited number of key species (Fig. 4, Fig. 5, Fig. 6).

The observed crop composition supports direct food access by providing households with a range of food crops for household consumption. The dominance of bananas, maize, cassava, yams, and beans suggests that households rely on a relatively small number of key crops as the foundation of their food supply, while additional crops may complement household diets and reduce dependence on market purchases.

The concentration on a limited set of crops despite overall diversification may reflect underlying socio-cultural factors shaping crop choice. Such patterns have been highlighted in a meta-study by Demongeot et al. (2025), which focuses on small-scale farmers with half of the studies conducted in Africa. According to Demongeot et al. (2025), farmers do not make crop choices solely based on commonly perceived economic value or yield considerations. They found that 90% of farmers reported values that fit into more than one category of decision-making factors (e.g. economic, agronomic, or cultural motivations). Furthermore, even though cultural preferences related to crop choice were reported by only 11% of farmers, they found that 64% of them ranked this category as the most important (Demongeot et al., 2025).

This indicates that the observed patterns in crop dominance and diversity across sub-counties cannot be attributed to cultural values alone but instead reflect multiple interacting factors. Instead, multiple factors influence crop choice, consistent with both the findings of Demongeot et al. (2025) and the sustainable livelihood perspective. Culture is not considered a sixth form of capital, but rather a factor that influences the five existing capitals and how they are put into use (DFID, 2001). Culture is embedded within policies, institutions, structures, and processes, which operate across levels from households to international scales and shape how livelihoods are structured and how resources are accessed and used (DFID, 2001).

Recognizing that farmers' decision-making is complex and influenced by cultural norms and values is essential for understanding the observed crop patterns and identifying constraints and opportunities for strengthening food security in the Mount Elgon area. It opens a discussions on how agricultural development can support more economically viable choices of secondary food crops, while at the same time acknowledging and working within the existing cultural context. This suggests that culture should not be viewed as an obstacle to be removed but rather recognize it as a fundamental part of farmers' decision-making processes.

Crop choice and sub-county

Sub-county was the only significant variable explaining variation in secondary food crop composition, while the other variables showed limited explanatory power. Although households varied along a gradient in the importance assigned to individual crops, households in Bushiyi were more strongly associated with bananas, cassava, yams, and sweet potatoes, whereas households in Sipi and Buginyanya placed greater emphasis on potatoes, maize, beans, and onions. In contrast, households in Bufumbo tended to assign greater importance to crops such as pumpkins, groundnuts, chili, and sugar cane (Fig. 3).
Sub-county is a complex variable, as it encompasses a mix of livelihood conditions such as natural capital (e.g. soil type, environment, slope), social capital (e.g. networks and communities), physical capital (e.g. infrastructure, equipment, market access), financial capital (e.g. income and access to credit and loans), and human capital (e.g. education level, farming knowledge, health status). Together, these dimensions shape the local agricultural context in the sub-counties and influence crop choices. However, it remains unknown which exact factors within sub-counties drive the differences in secondary food crop composition, as this has not been examined directly in this analysis. Nevertheless, the significance of sub-county suggests that secondary food crop composition is shaped by multiple interacting livelihood factors that influence cropping patterns at sub-county level. While more similar conditions within sub-counties are associated with more similar crop groups, variation between households still reflects a continuous gradient in crop composition.

Previous studies may provide insights into the factors underlying these differences in secondary food crop composition across sub-counties. Environmental factors such as altitude have been found to influence crop choices at Mount Elgon, as it is a proxy for temperature and precipitation (Rahn et al., 2018, Sarmiento-Soler et al., 2020, De Bauw et al., 2016). Even though the studies focus on Arabica coffee, it still highlights how the varying altitudes of Bushiyi, Sipi, Bufumbo, and Buginyanya (1346–1890 m) influence farmers' crop decisions, as they must adapt their crop choices and farming practices

to the different climatic and agroecological conditions associated with altitude. This may help explain the observed crop pattern in Bufumbo, which is located at a lower altitude, where households were especially associated with a crop group consisting of pumpkins, groundnuts, chili, and sugar cane (Fig. 3). Lower altitude might create agroecological conditions more suitable for the cultivation of these crops.

In addition, Rahn et al. 2018 highlights that altitude is also connected to distance to urban markets. Sub-counties located at lower altitudes tend to be closer to urban markets, while farming households located at higher altitudes are more strongly shaped by self-sufficiency and reliance on subsistence crops (Rahn et al., 2018). This suggests that when farmers are closer to the market they have a better awareness of market trends and therefore influence crop choices (Buckmaster et al., 2014). For example, Buckmaster et al. (2014) found that tomatoes, potatoes, and onions are often cultivated closer to market, whereas beans and maize remain profitable over greater distances (Buckmaster et al., 2014). Sipi and Bufumbo are the two sub-counties located closest to larger urban markets. The association of Sipi with potatoes and onions (Fig. 3) is consistent with findings by Buckmaster et al. (2014), who found that such crops are often cultivated closer to markets. Although the relationship is less clear for Bufumbo, it is possible that market access is among several factors that may influence crop choice across sub-counties.

These findings can be linked to a livelihood perspective through differences in natural and physical capital. Natural capital, including altitude, climate, and agronomic conditions, shapes livelihood strategies by influencing what crops are most suitable to cultivate. Physical capital, such as infrastructure and distance to markets, influences access to markets and services, the availability of agricultural inputs, and farmers' ability to engage in market activities and stay informed about market trends. In this case, both natural and physical contribute to shaping financial capital, by influencing crop choice, market orientation, and income-generating opportunities.

Overall, variation in secondary food crop composition across sub-counties appears to be shaped by a combination of agroecological conditions and market-related factors. This highlights how crop choices are driven by multiple environmental and socioeconomic dimensions rather than a single explanatory variable.

Crop choice and education

Even though the PCoA showed no clear pattern in education level (Fig. 3), agricultural knowledge and advisory services may influence the choice of secondary food crops and help explain differences in crop

composition across sub-counties suggested by existing research (Benin et al., 2007, Buyinza et al., 2021, Kyazze et al., 2024). Benin et al. (2007) investigated the impact of agricultural advisory and found that more than 50% of the farmers participating in the advisory program chose at least one new crop species after receiving advisory, while this figure was only 32% for the farmers that did not participate in the advisory program. These findings suggest that access to agricultural advisory services and education influence farmers' awareness and willingness to introduce new crop species. This relationship can be understood through the livelihood perspective, as differences in human capital influence households' crop choices, even when such effects are not visible in PCoA results.

It could be expected that higher levels of education facilitate the adoption of new agricultural practices and innovation in crop choices. However, despite Bufumbo being the sub-county that cultivated the most rare crops (Fig. 6), the results show no clear pattern between higher education level and cultivation of rare crops. Bufumbo is in fact the sub-county with the lowest education level (Fig. 2). However, education in this study has only been measured using the quantitative categories of primary, secondary, and higher education and does not capture agricultural training or the quality of education. This suggests that, despite lower general education level in Bufumbo, other forms of knowledge development, such as agricultural training and external support from organizations, might still have played an important role in the introduction of rare crops in the area.

The cultivation of rare crops in Bufumbo may also be influenced by traditional agricultural knowledge and local innovation. In the literature, this is often discussed under concepts such as indigenous knowledge, ethnoscience, and local innovation (Altieri, 1993, Sumane et al., 2018, Critchley, 2000, Sillitoe, 1998). Critchley (2000) demonstrates examples of local innovation among farmers in Uganda, Kenya, and Tanzania, showing that farmers possess extensive agricultural knowledge and play an active role in innovation processes. However, this is often underrecognized compared to external scientific knowledge (Critchley, 2000). Farmers frequently combine their own experiences and ideas with practices observed elsewhere to adapt and optimize production while conserving resources (Critchley, 2000). In the case of Bufumbo, the cultivation of rare crops may therefore not only be linked to external agricultural support, but also to locally embedded human capital in the form of agricultural knowledge and innovation.

The adoption of new crop species may lead to these becoming relatively important for the households. Some secondary food crops are mentioned by relatively few households but still receive relatively high

importance scores (Fig. 4). This suggests that crops cultivated by fewer households are not necessarily less important within the households that grow them and newly introduced or less common crops may still play an important role in household production once adopted.

The benefits of farmers' locally embedded agricultural knowledge depend on the extent to which such knowledge is shared. In this regard, social capital plays an important role, as networks and relationships facilitate the exchange of valuable knowledge, experiences, and agricultural practices among farmers. This knowledge exchange helps to preserve and spread local knowledge and may thereby facilitate the introduction and adaptation of new crops. An example of such a knowledge exchange is South-South cooperation which is defined as "a process whereby two or more developing countries pursue their … capacity development objectives through exchanges of knowledge, skills, resources and technical knowhow … for their individual and/or mutual benefit within and across regions" (UN, 2016). The advantage of South-South learning is that it is built on solidarity, equality, and mutual benefits (UN, 2016) which may foster trust and lead to more effective outcomes (Pretty and Ward, 2001). Furthermore, this type of knowledge exchange often takes place among farmers operating under similar conditions, such as cultural and agronomic ones, thereby increasing the relevance and applicability of the knowledge shared (UN, 2016).

In relation to the livelihood perspective, this type of farmer-to-farmer knowledge exchange leads to a dynamic and reinforcing relationship between human and social capital. Within South-South cooperation, farmers draw on their social capital through networks and relationships that facilitate the exchange of knowledge, thereby strengthening human capital. At the same time, when farmers mobilize their human capital by sharing knowledge and actively engaging in these networks, trust and social relations are reinforced, which strengthens social capital (Pretty and Ward, 2001). At the same time, South-South cooperation may strengthen financial capital, as it can increase effectiveness and reduce costs (UN, 2016). Rather than viewing formal advisory systems based on North-South cooperation as a competing approach to South-South cooperation, they should be understood as complementary mechanisms that can contribute to common objectives (UN, 2016).

Overall, South-South cooperation can serve as a livelihood strategy by strengthening livelihood assets, thereby enhancing livelihood outcomes. In the context of this study, such knowledge exchange may facilitate the sharing of experiences related to secondary food crops, potentially supporting the adoption

of new crop species. This may in turn contribute to reduced vulnerability to environmental and economic shocks as well as improved direct access to food.

Crop choice and gender

There were different crop preferences between the genders where male household heads found beans, onions and cabbage particularly important relative to female household heads (Fig. 7). On the other hand, females considered crops like yams, eggplant, maize, and bananas more important compared to the males. In Uganda, men and women have different social roles and responsibilities, as the men mainly focus on the cash crops, while women focus on subsistence crops (Nakazi et al., 2017, Okonya and Kroschel, 2014). This pattern is reflected in the results, where men prioritize beans and onions which are mainly cash crops, while women prioritize yams, maize, bananas which are widely used for household food consumption (Patrick Kayima: personal communication: 15/05/2026). Traditionally, beans were considered a subsistence crop, therefore classified as a woman's crop (Nakazi et al., 2017). Driven by increasing market demand and government initiatives, beans have increasingly transitioned from a subsistence crop to a cash crop, being sold in local markets as well as for export, with a growing involvement of men in production (Nakazi et al., 2017). However, no crop is exclusively either a cash or subsistence crop, as this depends on market conditions; when demand is high, farmers tend to sell, whereas in cases of low demand or low prices, it is more likely to be used for household consumption (Sorensen, 1996, Janvry et al., 1991). This highlights the flexibility of crop use within rural livelihoods.

Overall, the observed gender differences in crop choice and importance reflect differentiated livelihood strategies within households, where men and women prioritize different crops in relation to income generation through cash crops and direct food access through subsistence crops. This pattern is shaped by broader cultural norms regarding gender roles in agriculture. The results further highlight that crop choices are shaped by intra-household dynamics and gendered divisions of labor that influence how agricultural resources are prioritized and managed.

Methodological constraints

While the analysis provides insights into how livelihoods influence on secondary food crop choice, it is important to consider the methodological constraints when interpreting the results. These constraints relate to which livelihood capitals were included in the analysis and how they were operationalized. Out of the five livelihood capitals, the analysis focused on human capital and natural capital indicators.

However, all livelihood capitals are interdependent, as presented in the theory section. Therefore, a more comprehensive analysis would have included all five capitals.

Human and natural capital, as analyzed in this study, are also constrained by methodological limitations. The AfPEC project encompassed a limited number of livelihood variables, all of which are quantitative, resulting in a limited representation of human capital and especially natural capital. Consequently, the livelihood variables function as simplified indicators of selected dimensions of livelihood capital rather than comprehensive representations. Therefore, the data used can only reflect a fraction of the complexity in the farmers' livelihoods and secondary food crop choices.

Beyond these general data limitations, it is also important to consider what the analytical results based on the selected livelihood variables capture and what they do not capture in relation to influences on secondary food crop choices. The absence of clear relationships in the analysis between the non-significant livelihood variables and secondary food crops does not necessarily imply that these factors are unimportant but instead reflect the complexity of livelihood decision-making. Education level, for example, only reflects a quantitively aspect of education and does not capture the quality or relevance of the education received. Consequently, important dimensions of human capital are not reflected in the analysis. Similarly, other non-significant variables may still influence crop choices in an indirect or complex way and are not fully captured by the PCoA. Even though direct livelihood indicators, such as education level and sub-county, do not fully capture the complexity of livelihood decisions, they make the analysis and comparison more straightforward. More indirect indicators, such as social networks, tradition, culture, and trust in advisory services are more time-consuming to measure, difficult to operationalize, and demanding to analyze. However, incorporating these indicators would lead to a more holistic understanding of farmers' decision-making on secondary food crops and provide a more nuanced interpretation of how livelihood capitals shape livelihood outcomes, particularly direct food access and household food security.

In response to these quantitative limitations, previous studies have shown that qualitative approaches can provide a more detailed understanding of farmers' decision-making. Such qualitative factors as tradition and culture help capture nuances in farmers' decision-making that quantitative data often fail to capture (Singh et al., 2016, Agrawal et al., 2021, Voorhaar et al., 2025). For example, Singh et al. (2016) conducted in-depth life stories interviews to explore complex topics such as family history and intra-household dynamics that influence agricultural decisions. Agrawal et al. (2021) carried out semi-

structured interviews that allowed for an open and flexible interview that could enable unanticipated insights. These researchers also participated in informal interactions with farmers, including market visits, cooking activities, and shared meals, to triangulate and validate data from the formal interviews.

Despite these studies being conducted in India under different livelihood conditions than those of farmers in Uganda, they demonstrate that, although such approaches are time-consuming and subject to practical constraints, it is still possible to capture complex qualitative dimensions relevant to the context of Mount Elgon. This suggests that future research on secondary food crops could benefit from complementing the present data with in-depth qualitative approaches to achieve a more comprehensive understanding of livelihood strategies and crop choices.

Another methodological constraint concerns the handling of missing and incomplete data within the dataset. Due to missing or incomplete data resulting from different ways of sampling data, secondary food crops that were not assigned a value from 0-5 during the interview process. These cases were instead given a crop importance value of 0.5, similar to the correction from 0 to 1 garden in the dataset. This might have influenced the results, as it does not accurately reflect the true variation in importance between these crops.

Overall, the methodological limitations outlined above suggest that the analysis provides a partial representation of livelihood influences on secondary food crop choices. While the selected livelihood variables capture only parts of human and natural capital, other livelihood capitals and more qualitative aspects remain unaccounted for. Consequently, the results should be interpreted accordingly, highlighting general patterns and aspects of farmers' decision-making on secondary food crops rather than fully explaining the complexity.

Future research

The relevance of applying mixed methods has already been highlighted in relation to the use of quantitative livelihood variables and complementary qualitative research, which together provide a more comprehensive and nuanced understanding of farmers' secondary food crop choices. Future research could also explore additional dimensions of agroecological conditions, including soil type and water availability. It would also be relevant to investigate the role of market access and market conditions.

Beyond understanding the factors shaping crop choice, future research could also examine the

implications of different crop compositions for household food security and nutrition. While some of the most important secondary food crops for households are predominantly starchy, such as bananas and yams, others, such as beans, provide higher protein content. Enhancing food security is therefore not only a question of direct access to secondary food crops, but also of the nutritional composition of the crops available to households. Future research could therefore investigate the nutritional composition of secondary food crops in greater detail and assess their contribution to dietary quality and nutrition. In this context, it may also be relevant to explore whether rare crops identified in Bufumbo and Buginyanya provide additional nutritional benefits compared to more commonly cultivated crops and whether they have potential for wider cultivation.

Overall, further research could contribute to a more comprehensive understanding of both the factors shaping secondary food crop choices and the implications of these choices for household food security and nutrition.

Conclusion

The households at Mount Elgon cultivated a diverse range of secondary food crops, including bananas, cassava, maize, beans, yams, sweet potatoes, potatoes, cabbage, and a range of less frequently cultivated crops. These crops contributed to direct food access and household self-sufficiency, while also supporting income generation depending on market conditions.

Crop composition varied across households, and sub-county was the only significant factor explaining this variation. This suggests that local agroecological and socioeconomic conditions play an important role in shaping farmers' crop choices. In contrast, the selected indicators of human capital (age, education level, and number of children living at home) and natural capital (land area and number of gardens) explained only a limited proportion of the variation in crop composition. This suggests that farmers' crop choices are influenced by a broader set of interconnected livelihood factors than those captured in this study, including local agroecological conditions, market access, social relations, cultural preferences, and farmers' knowledge.

Although households overall cultivated many different secondary food crops, crop production was concentrated around a limited number of key crops. Crop importance and crop diversity varied across households and sub-counties, with bananas, maize, cassava, yams, and beans being the most important crops.

Based on these findings, improving direct food access and household food security require consideration of the local context in which farmers make crop choices. Since secondary food crop composition appears to be shaped by multiple interacting livelihood factors, strategies aimed at strengthening direct food access should account for local agroecological and socioeconomic conditions, as well as farmers' existing livelihood strategies and constraints. Such efforts may benefit from locally adapted advisory services and knowledge exchange between farmers. Furthermore, future research could examine how the secondary food crops contribute to improved food security through their nutritional value and could enhance understanding of farmers' crop choices by incorporating qualitative approaches that capture social, cultural, and contextual factors.

Perspectives

Sub-county is a complex variable encompassing diverse livelihood conditions. This suggests that food security strategies should avoid general solutions and instead be developed in collaboration with farmers and tailored to local agronomic, socio-economic, and cultural conditions. However, these factors should be understood as shaping rather than determining farmers' choices. This perspective allows for interventions that both build on and challenge existing secondary food crop selection practices to support more resilient and food-secure agricultural systems.

The presence of rare crops in Bufumbo may indicate that local innovation and knowledge play an important role in shaping cropping patterns. Rare crops may contribute to additional income opportunities and increase dietary and crop diversity, which could potentially strengthen resilience to stress and shocks. This highlights an opportunity to strengthen food security through better acknowledgement, documentation, and integration of local knowledge. Such efforts can support the sharing of existing farm-led practices across sub-counties, thereby enhancing both resilience and food security.

Although agroforestry systems are characterized by crop diversification, a limited number of crop species dominate household production. A similar tendency can be observed in the literature, which often focuses on coffee and bananas as the dominant crops in these systems. This suggests a potential opportunity to strengthen food security by improving the utilization of and market potential of rare crops. Incorporating a wider range of crop species could be supported through agricultural training, improved access to seeds and local markets, and knowledge exchange on cultivation practices and the potential economic benefits of rare crops. Strengthening the use of a wider range of crops may contribute to greater dietary diversity, increased resilience, and reduced dependence on a few dominant species.

Women appear to influence the choice of secondary food crops through different crop preferences than men. Although only a limited number of women were represented in the analysis, the findings are in line with existing literature. Therefore, actively including women in agricultural training, could contribute to improved food security. Men and women may have different knowledge and experiences related to crop production and household food needs, which influence agricultural decision-making. Strengthening women's participation in training and decision-making may influence crop choices towards greater crop diversity, which can improve household dietary diversity, resilience, and ultimately food security.

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Appendix

Appendix 1 - full list of secondary food crops

All secondary food crops
Bananas
Beans
Maize
Potatoes
Kale
Cabbage
Onions
Cassava
Spinach
Yams
Passion fruit
Egg plant
Rice
Sweet potatoes
Ground nuts
Tomatoes
Pumpkins
Chili
Sugar cane
Soy beans
Vanilla
Ginger
Carrots
Black nightshade
Sesame seeds
Sunflower
Cow peas
Wheat
Millet
Sorghum
Cocoa
Rosemary
Pineapple
Basil
Okra
Elephant grass
Green pepper

Appendix 2 - Number of mentions and percentage of education levels across sub-counties

Sub-county	Education level	Number of mentions	Percentage
Bududa	Primary education	15	50
Bududa	Secondary education	10	33
Bududa	Higher education	5	17
Bufumbo	Primary education	11	55
Bufumbo	Secondary education	8	40
Bufumbo	Higher education	1	5
Buginyanya	Primary education	13	54
Buginyanya	Secondary education	7	29
Buginyanya	Higher education	4	17
Sipi	Primary education	7	32
Sipi	Secondary education	9	41
Sipi	Higher education	6	27

Appendix 3 - Mentions and average importance of secondary food crops

Crop	Mentions	Average Importance
Bananas	91	3.82
Cassava	68	2.57
Maize	63	2.78
Beans	61	2.02
Yams	56	2.46
Sweet potatoes	28	1.02
Potatoes	21	1.81
Cabbage	20	0.92
Pumpkins	15	0.50
Tomatoes	15	0.83
Egg plant	14	0.93
Onions	13	1.46
Passion fruit	12	0.71
Ground nuts	10	0.50
Rare	10	1.25
Spinach	7	1.00
Chili	6	0.50
Kale	6	1.00
Sugar cane	6	0.50
Rice	5	1.20
Soy beans	3	0.67