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FARMERS' PRACTICES IN RELATION TO CROP INTENSIFICATION INNOVATION WITHIN POTATO PRODUCTION SYSTEM IN UGANDA

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Abstract

The disparity between actual and potential potato crop yield is still persistent in Uganda. This is attributed to existing smallholder farmers' potato production practices, notably poor-quality seed and limited use of fertilizers that cripple yield. Experimental studies indicate that utilization of high-quality seed, adequate soil fertility enhancement practices, and suitable companion cropping strategies can close the yield gap. This study sought to establish and document the existing smallholder farmers' practices and techniques in relation to potato crop intensification production system in the districts of Rubanda, Kabale, and Rukiga. Data were collected through six focus group discussions (FGDs) with smallholder potato farmers and analyzed using a combination of thematic analysis utilizing ATLAS.ti software and descriptive statistics. Results indicated that home-saved seed recycled from previous harvests was the main potato seed source thus because it was perceived as cheap and guaranteed seed availability. Relatedly, farmers mainly utilized small size tubers because small tubers cover (plants) a wide area compared to medium and large size tubers but little knowing that small from recycled seed sources is usually small due to degeneration because of overuse and or diseased. Maize and sorghum were the main potato-based intercrops mainly for food security reasons compared with potato-legume based intercropping system that guarantees soil fertility. Similarly, while there was general limited use of synthetic fertilizers, farmers could also not ably differentiate the different types of fertilizers used by name but by coulour and shape leading to a risk of inappropriate use such as using wrong fertilize, underuse or overuse. Relatedly, in addition to generally low use of organic manure, farmers applied farmyard manure by grazing and tethering livestock in gardens reserved for potato

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production a few months before planting the potato which leads to leaching, erosion, volatilization, and poor distribution. These practices implied that farmers lacked basic knowledge on good agronomic practices regarding potato production. Based on the results, it was recommended that integrated extension programs are adopted to be able to provide comprehensive training on quality seed, proper cropping strategies and soil fertility management practices.

Keywords: *Agronomic practices, comprehensive training, extension programs, farming system, potato production, smallholder farmers.*

1.1 INTRODUCTION

Globally, potato (*Solanum tuberosum* L.) stands as a pivotal crop among smallholder farmers, contributing significantly to both food security and economic sustenance (Mugisha *et al.*, 2017). Its importance is underscored by its ranking as the third most vital crop worldwide, following rice and maize (Shaaban & Kisetu, 2014). Its production has witnessed half a century of improvements with its yield annually steadily increasing by 2% mainly due to improved seed systems (Devaux *et al*., 2021).

In Africa, potato production over the last 20 years has more than doubled mainly resulting from increased acreage (Campos & Ortiz, 2019). This increase is also attributed to other factors ranging from good weather, fertile soil, and enabling policy framework that strengthens institutional and legal regulatory frameworks that support variety development and seed production (Kisakye *et al*., 2020). For instance, in Kenya, the government instituted a range of policies, regulations, and investment strategies to expand the production volumes and value of potato in the country over the past decade (McEwan *et al*., 2021; Muthoni *et al*., 2010).

In Uganda, potato holds a prominent place as the third most consumed food crop, offering relatively affordable source of essential food nutrients such as carbohydrates, dietary fiber, lipids, proteins, minerals, and vitamins (Munyuli *et al*., 2017). However, its current yield, averaging at 4.3-7.1t/ha, significantly falls below its potential (25-30t/ha) (Namugga *et al.*, 2017). This disparity in yield is attributed to various factors, among them being persistent reliance on traditional production practices by smallholder farmers (Aheisibwe *et al*., 2016).

In Southwest Uganda where about 60% of the national potato output is obtained, farmers' over dependence on traditional potato production practices, including poor quality seed, inappropriate use of agrochemicals, unsuitable intercropping systems cannot be overemphasized (Nakibuule *et al*., 2022; Srivastav, 2020; Aheisibwe *et al*., 2016). Whereas some traditional crop production methods may have some cultural significance and historical precedence, their coherence in maximizing crop yield and productivity in the context of smallholder farmers is ambiguous.

Therefore, this study sought to establish and document existing farmers' potato production practices in relation to potato crop intensification to answer questions on what agricultural practice farmers use, how they implement them, and why to provide a foundation for enhancing uptake of contemporary practices that ultimately improve productivity and yield.

1.2 Theoretical and conceptual frameworks

Much of farmers' practices remains undocumented which not threatens its continuity but also to establish their cultural significance and historical precedence and coherence to maximize crop yield and productivity in the context of smallholder (Bhatia, 2024). In this kind of production system, farmers tend to emphasize livelihoods through livelihood assets (natural. Physical, human, financial and social capital) that shape the kind of practices to adopt (He & Ahmed, 2022). Such practices usually include intercropping, soil fertility management and pest and disease management and traditional crop varieties that are more adapted to local conditions. However, farmers' practices usually have limited focus on documentation and preservation to preserve them for continued use and transitioning to future generations but also to integrate them with modern agricultural practices for a more resilient and sustainable food system.

There are multiple entry points for promoting crop yield, productivity, and resilience for smallholder farmers (Figure 1). For instance, access to improved varieties and quality seed is central to agricultural development, economic growth, and poverty reduction particularly, for smallholder farmers (Bagamba *et al*., 2023).

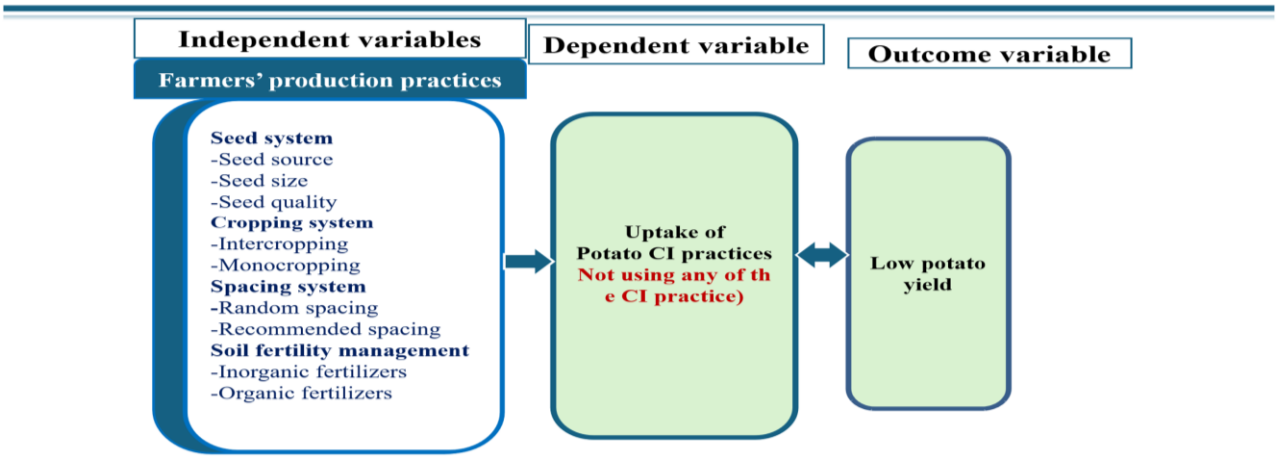

Figure 1 Influence of farmers' practices on potato yield and productivity

Source: Adapted from Okello *et al.* (2016)

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Traditionally, smallholder farmers are usually limited in many agricultural production contexts such as knowledge and other production inputs such as seeds and fertilizers. As such, proponents of traditional knowledge argue that this kind of knowledge should not be developed or harnessed as a substitute for scientific knowledge but rather to complement formal knowledge for enhanced resilience in smallholder farming systems (Makate, 2019). The dependency on farmers' practices has been responsible for low yield and productivity achievable by smallholder farmers (Molnár & Babai, 2021; Reyes *et al*., 2020). Thus, smallholder farmers remain imbedded in abject food insecurity and low household income.

2 METHODS AND MATERIALS

2.1 Research Design

An exploratory descriptive research design was adopted to conduct the research using FGDs following the launch of the CARP+ Project potato crop intensification intervention to establish the 'what', 'how,' and 'why' that were central in this study. According to Sanya *et al*. (2017), a research design is a framework that supports production of evidence-based knowledge. Different research designs exist in literature such as experimental designs, longitudinal designs, comparative designs, case study designs cross-sectional designs. Based on the 'what', how', and 'why' questions to be established in the study, the study followed a qualitative method to collect and analyze the data.

2.2 Study Area

The study was carried out in Southwestern Uganda at three sites purposively selected across three districts: Rubanda, Kabale, and Rukiga following the launch of the Community Action Research Programme Plus (CARP+) Project. This initiative aimed to improve the uptake of potato crop intensification innovation within the potato farming system among smallholder farmers through targeted research, demonstration, training, and dissemination activities. These locations were chosen due to their integration of farmers earmarked to participate in the project, prevalence of diverse potato farming activities, and the access of local stakeholders who collaborated with the CARP+ project implementation. Additionally, these districts are geographically diverse, encompassing different potato farming systems and socioeconomic conditions, thereby enhancing the robustness and generalizability of the study findings. Overall, the deliberate choice of study sites within Southwestern Uganda underscores the systematic and rigorous approach employed to investigate how smallholder farmers accept to use or reject innovations.

2.3 Study Population

The study targeted smallholder potato farmers who actively participated in the CARP+ Project. These were selected based on their knowledge of the CARP+ Project implementation activities and experience in potato production.

2.4 Data collection methods

The study adopted a qualitative method to collect data. Data were gathered using focus group discussions (FGDs), each involving 8 potato farmers. These participants were purposefully selected based on their active involvement in potato farming activities and active involvement in the CARP+ Project activities. An interview guide served as the foundation for the FGDs, guiding discussions and ensuring consistency in data collection across sessions. The moderator (researcher) skillfully facilitated the dialogues by posing relevant questions and employing probing techniques to elicit detailed narratives from participants. To ensure accuracy, a voice recorder was used to record the interview session after seeking informal consent from respondents, and notetaking was done by a research assistant. This approach enabled the exploration of participants' perspectives, experiences, and insights regarding production practices used by smallholder farmers.

2.5 Data analysis

Data analysis was conducted using thematic analysis and ATLAS.ti and descriptive statistics to generate frequencies and percentages. These methodological approaches were chosen to comprehensively explore the qualitative data while providing quantitative summaries where applicable. Thematic analysis was employed to identify recurrent themes and patterns within the data. Initially, transcripts were translated from Rukiga dialect and accurately reviewed to develop a coding framework. Following this step, segments of data were systematically coded according to emerging themes. Through an iterative process, codes were refined and organized into key themes that were central to the data. Descriptive statistics were further utilized to provide quantitative summaries of certain aspects of the data. Frequencies of themes and sub-themes were analyzed to identify their prevalence within the dataset. Particularly, where applicable, measures mainly percentages were computed to quantify the distribution or central tendencies of specific themes. According to Braun & Clarke (2023), integration of thematic analysis and descriptive statistics allows for a comprehensive and multifaceted analysis of the data. Thematic analysis facilitates the exploration of underlying meanings and patterns (Braun & Clarke, 2006), while descriptive statistics provide quantitative insights that complement and enrich the interpretation of findings (Siedlecki, 2020). Thus, this methodological synergy enabled a robust examination of the qualitative data, yielding important insights into the practices and contemporary techniques of smallholder farmers used in potato production.

3 RESULTS AND DISCUSSION

3.1 General perception of smallholder farmers toward potato crop intensification innovations before and after CARP+ Project

Survey results indicated a significant shift in farmers' perception from relying on traditional potato production practices from 51.3% before CARP+ Project (<2018 season A) to 13.6% (after CARP+ Project intervention) (Figure 2).

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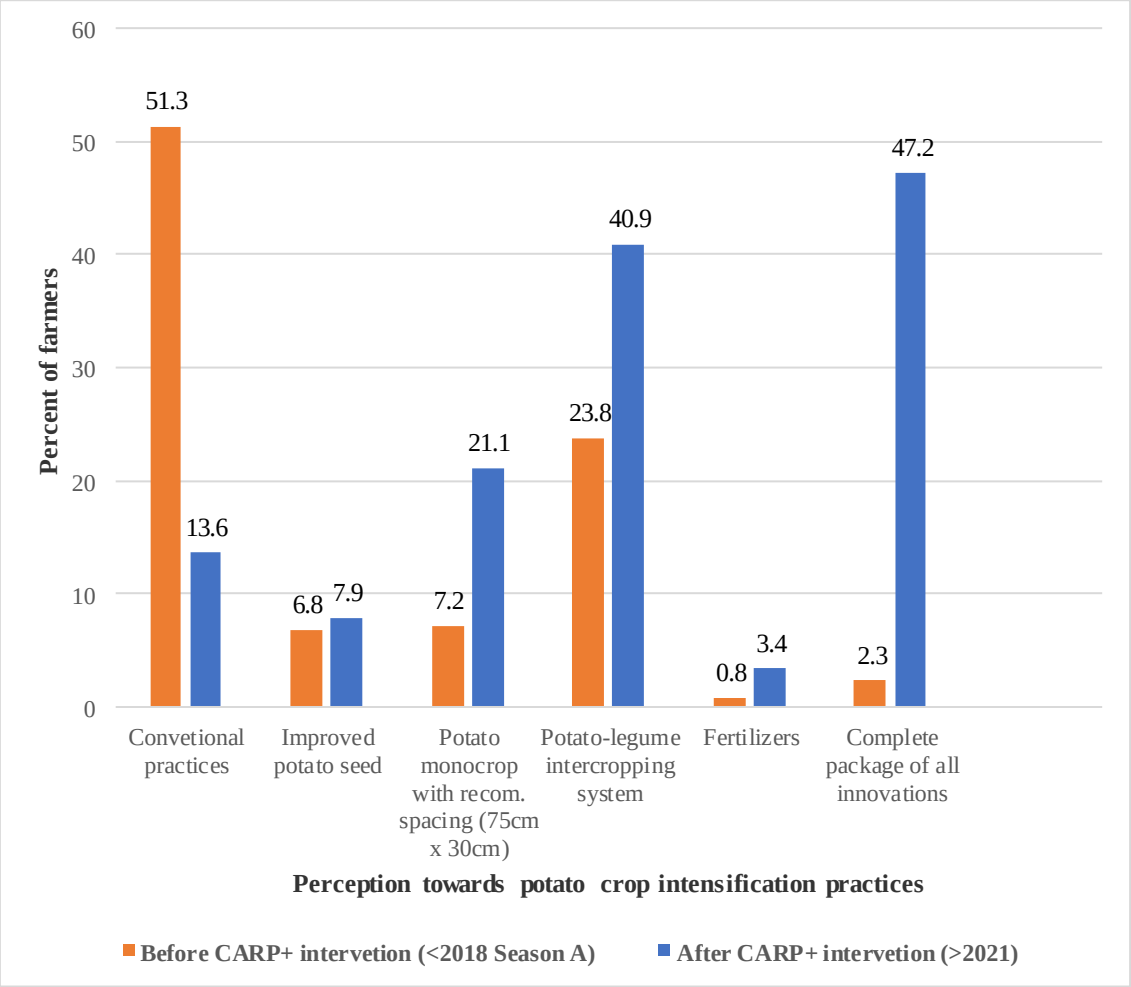

Figure 2. General perception of smallholder farmers toward potato crop intensification innovations before and after the CARP+ intervention

Source: Survey data, 2022

There also a tremendous change in positive shift in farmers' perception from using traditional practices from 2.3% (<2018 season A) to uptake of a complete package of innovations (47.2%) after the project. Similarly, there was notable positive change in perception towards potato-legume intercropping system from 24 to 41% and potato monocropping with recommended spacing (75cm x 30cm) improved from about 7 to 21% respectively. This positive towards uptake of improved practices could probably be attributed to the extension services and demonstration activities that were rendered to farmers during project implementation period. However, much as there was a slight improvement in perception in use of improved seed from research station (7 to 10%) and use of fertilizers (0.8 to 3.4%), their uptake remained comparably lower. This negative perception was caused by high cost of this input, accessibility and, the small-scale nature of most farmers and lack of skills and experience to apply these inputs. It is, therefore, imperative that clear extension messages and information dissemination to create awareness on benefits of using quality seed and fertilizers coupled with strengthening supply chain and distribution networks to ensure that quality seed and fertilizers are easy to access and readily available.

3.2 Farmers' practices used in potato production

3.2.1Potato seed sources commonly used by smallholder farmers

Results from FGDs indicated that there were about eight potato seed sources commonly used by smallholder farmers. These potato seed sources ranged from home-saved sources where farmers recycle part of the previous harvest to use as seed in subsequent season, buy from local stores and local markets, buy from other/fellow farmers, farmer groups such as cooperatives, and research stations mainly Kachwekano-ZARDI, buy from extension agents and use volunteer crops as demonstrated in Figure 3.

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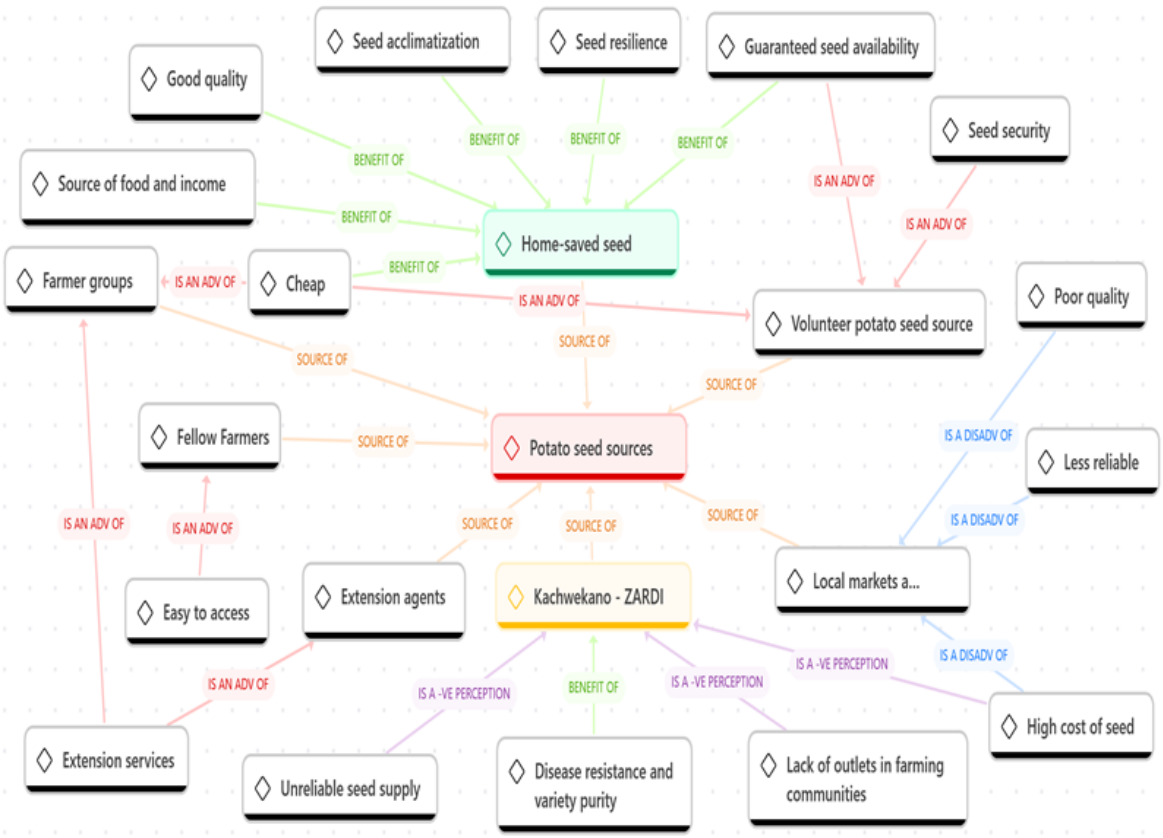

Figure 3. Potato seed sources commonly used by smallholder farmers in the study area

i) Home-saved seed (potato seed recycled from previous harvest)

Home-saved potato seed source, a practice whereby farmers keep part of the seed from previous harvests to use as seed in the next planting season was mainly liked by smallholder farmers from Rubanda, Kabale, and Rukiga districts respectively for various reasons such as low cost, seed acclimatization, seed and food security. After harvesting, farmers usually sort out marketable size tubers for sale and/or household consumption and leave small- size tubers (unmarketable size) preserved as 'seed' during the next planting season. During seed storage in a way of seed preservation, farmers poured the seed on dry grass or on well laid timber placed in a well-aerated space either in the main house or farm store to avoid direct contact with soil and allow sprouting. Some farmers also sprinkle wood ash to prevent rotting and encourage sprouting. Home saved potato seed source was mostly preferred for various reasons mainly:

Being cheap: It reduces the cost of production because farmers do not need cash to buy and transport seed at the time of planting, the seed is readily available at home.

> "*When I have kept my seed, it becomes cheaper for me, I don't have to buy seed which is always expensive, especially at planting time. Am also sure of the seed variety and am guaranteed of disease-free seed"* (FGD, Rukiga district).

Guaranteed seed availability: The system guarantees seed availability at the time of planting, and it saves farmers from being cheated by traders in the market.

> *"I was disappointed once by Kachwekano-ZARDI, I went there two years ago at the beginning of the planting season, but they did not have any seed. From that time, I have never gone back for seed. That season, I missed on growing potato as I could not get seed elsewhere because I was already late"* (A farmer, FGD Rubanda district).

Good quality: Farmers regarded potato seed from home-saved seed source as high quality in for variety because, free from damage by cutting/bruising/rotting, disease resistance, and yielding capacity because of the known history (Own farm).

> *"Can you imagine! sometimes you plant Rwangume potato variety, but you end up harvesting Kinigi variety. Other potato seed sources are not reliable. There is a mixture of varieties. They even don't remove the bruised ones, hence the rotting of seed"* (FGD, Rukiga district).

Source of food and income: Home-saved seed potato can be a good source of food during the food crisis. A farmer can also sell part of the seed to raise some money to cater for basic needs such as school fees (food and income security).

> "*Our children cannot sleep hungry when we have seed in the house. Even when they are chased from school, we must sell a small quantity and send children back to school*" (An elderly potato farmer in Kabale district).

Self-reliance: Farmers particularly women want to be self-reliant in terms of potato seed supply. By continuously saving their potato seed and attending some training on potato production, they obtain knowledge and technologies of potato seed production such as positive seed selection.

> *"I was taught by Caritas NGO how to make my own potato seed; I have to make sure that I reserve a small*

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portion of my harvest by spotting certain plants that look healthy when they are still in the garden, I mark them and harvest them either first or last and then reserve that harvest for seed for the next season. Such a method is called positive seed selection" (A male farmer in Rubanda District during FGD).

Seed acclimatization: Some smallholder farmers believe that because the local potato seed that is recycled over time has become more acclimatized to the local soil conditions in the area so are reluctant to buy new seed from other sources.

"We have been using our seed for many years, I think it is used to soils and weather. That's why we must keep our seed to get a better yield. We fear that we may get seed from other sources, and we lose everything" (FGD Rukiga district).

ii) Research station seed source

Study findings revealed that the research station mainly (Kachwekano-ZARDI) was the second used potato seed source by smallholder farmers because of resistance to disease and purity (uniformity).

"*Kachwekano-ZARDI does not supply seed to individual farmers but only deals with rich and big farmers who are organized in registered groups"* (FGD, Rukiga district).

iii) Local markets and local stores

Research findings from FGDs indicated that local markets and local stores were common potato seed sources in the study area because the seed sources were more accessible.

"I cannot trust potato seed which I do not know where it came from" (A female farmer during FGD in Kabale district).

However, the potato seed source was associated with some challenges such as poor quality due to mixed varieties, sometimes less reliable because of limited supplies, high cost, and inability to trace the origin of the potato seed.

iv) Volunteer crop potato seed source

A volunteer crop seed source was used mainly in Rukiga district. This is where farmers intentionally leave some potato tubers in the soil (garden) during harvesting as seed for the following cropping season. This potato seed source implies that no additional seed requirements are needed at the following planting. This method was commonly applied by women as a seed security measure.

However, with the prevalence of potato blight, which is a bacterial disease that significantly lowers potato yield, hence requiring that a given land is followed for at least three seasons before another potato is planted again to control this disease (Kwambai *et al*., 2023). Therefore, this method of preserving potato seed could be among the contributing factors for potato bacterial wilt disease among farmers.

v) Fellow farmer seed source

Fellow farmer seed source is where farmers obtain seed from fellow farmers who are perceived to have had healthy garden the previous season. This seed source was popular because farmers can observe and monitor the neighbor's garden (fellow farmer) and then book the seed based on the physical observation regarding the health status of the garden.

"When the neighbor's garden looks healthy in the garden, you have to book seed early enough by paying in advance to avoid missing out" (Farmer during FGD, Rukiga).

vi) Extension agent

Extension agent potato seed source was most common because extension agents usually offer more extension services such as how to plant, pest and disease control such as agrochemicals to use among others.

" *I like getting seed from extension agents because the agents can tell you how to plant and which chemicals to use to control pests and diseases"* (A male farmer FGD, Kabale)

Extension agent is where farmers rely on the extension agent as an individual to supply potato seed. The extension agents sometimes source potato seed they supply to their clients from either research stations or other sources such as other farmers, local markets and/or local stores.

"Sometimes, seed from extension agent rots before germination or starts drying shortly after germination. And you cannot report him because you don't have evidence that you bought seed from him or her. Government should help us" (FGD, Rubanda district).

This implies that this seed source sometimes may not offer the expected yield results to the farmers because it is recycled but disguised as quality seed. Because these individuals are not licensed to supply seed and there is no contractual agreement, farmers cannot hold extension agents liable for crop failure resulting from poor seed supplies.

vii) Farmer groups

This is where farmers obtain potato seed from organized farmer groups such as cooperatives and other farm-based organizations in their local communities. This source is preferred most because of its easy accessibility.

"*Our groups have helped us. You can even get seed on the morning of planting. You don't even need transport since it is near"* (FGD, Kabale district).

Therefore, despite its reputation for supplying high-quality potato seed with desirable traits, the research stations, including Kachwekano-ZARDI encounter skepticism among smallholder farmers due to issues such as cost, reliability, and accessibility. While the emphasis on disease resistance and variety purity is laudable, challenges related to its affordability and outreach by individual farmers pose significant barriers to uptake. Scientific investigation into its supply chain management is imperative to optimize the efficiency and effectiveness of research station-derived seeds not only to address farmers' needs but also to enhance agricultural productivity. Thus, smallholder farmers tend to find traditional potato sources, mainly home saved sources that are perceived as cheap, reliable, easily accessible and thus, more adoptable.

While home saved seed may be perceived as cheap, reliable, and easily accessible, it often lacks scientific traits such as disease resistance necessary for optimal agricultural productivity and resilience (Aheisibwe *et al*., 2016; Muthoni *et al*., 2022; Okello *et al*., 2016). Research station seed,, on the other hand, offer several key advantages that can significantly benefit smallholder farmers

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(Adolwa *et al*., 2019; Kuntosch & König, 2018; Oyetunde-Usman *et al*., 2021; Vandevelde *et al*., 2021). Potato seed from research stations is carefully bred and selected to possess desirable traits such as disease resistance, high yield potential, and adaptability to changing environmental conditions (Aheisibwe *et al*., 2015; Mastenbroek *et al*., 2021). Therefore, by utilizing such improved seed, smallholder farmers can enhance the quality and quantity of their potato yield, leading to increased incomes and food security. Further, improved seed sources contribute to the sustainability of agricultural systems by reducing the risk of crop failure due to pests, diseases, and environmental stressors. Research stations invest in rigorous quality control measures to ensure the purity and efficacy of their seeds, providing farmers with reliable planting materials that contribute to long-term agricultural sustainability (Muthoni *et al*., 2022; Vandevelde *et al*., 2021). Therefore, prioritizing the uptake of improved seed from research stations offer smallholder farmers an opportunity to overcome the limitations of traditional home saved seeds and unlock the full potential of potato cultivation, thus improved livelihoods and sustainable development of rural communities through enhanced improved agricultural productivity.

3.2.1.1 Perception of smallholder farmers towards research station (Kachwekano-ZARDI) as a credible source of improved potato seed

Survey results revealed that there was a significant regional variation in the preferred sources of potato seed among farmers in the Rubanda, Kabale, and Rukiga districts (Figure 4).

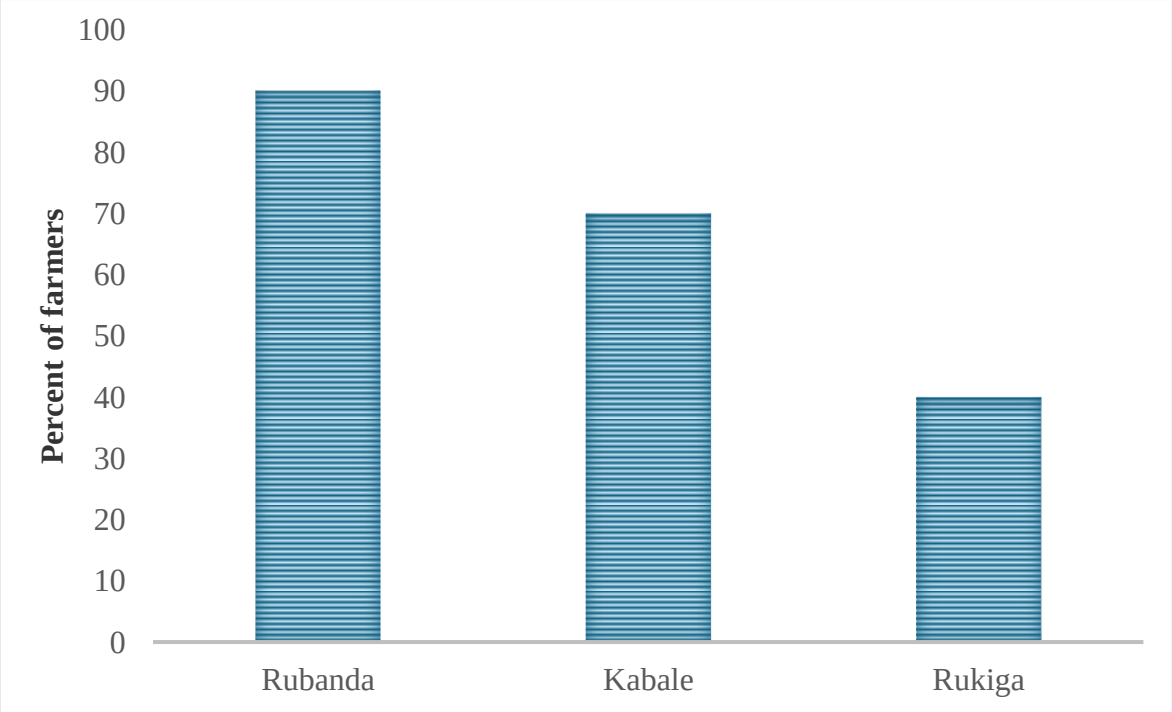

Figure 4: Preference for research station (Kachwekano-ZARDI) as credible source for quality seed

Source: *Field data, 2022*

Specifically, research station including Kachwekano-ZARDI are highly preferred in Rubanda and Kabale (90 and 70% respectively) but less preferred (40%) in Rukiga. This preference discrepancy was probably associated with location of Rukiga district being far away from Kachwekano-ZARDI, leading to additional transaction costs related to transport and travel time to and from the research station. Transport costs and other logistical challenges play a crucial role in the uptake of new practices because of the additional costs involved

(Juma, 2015). Thus, by reducing the distance that farmers need to travel to access an input significantly improved its uptake (Vandevelde *et al*., 2021). This finding also feeds into the need for Kachwekano-ZARDI to extend its distribution networks by partnering with local stores and local markets to ensure all the services offered by the institute such as supply of quality declared seed and extension services are extended nearer to the remote farmers through public private partnerships (PPP) arrangement.

3.2.2 Potato tuber size planted as seed by smallholder farmers

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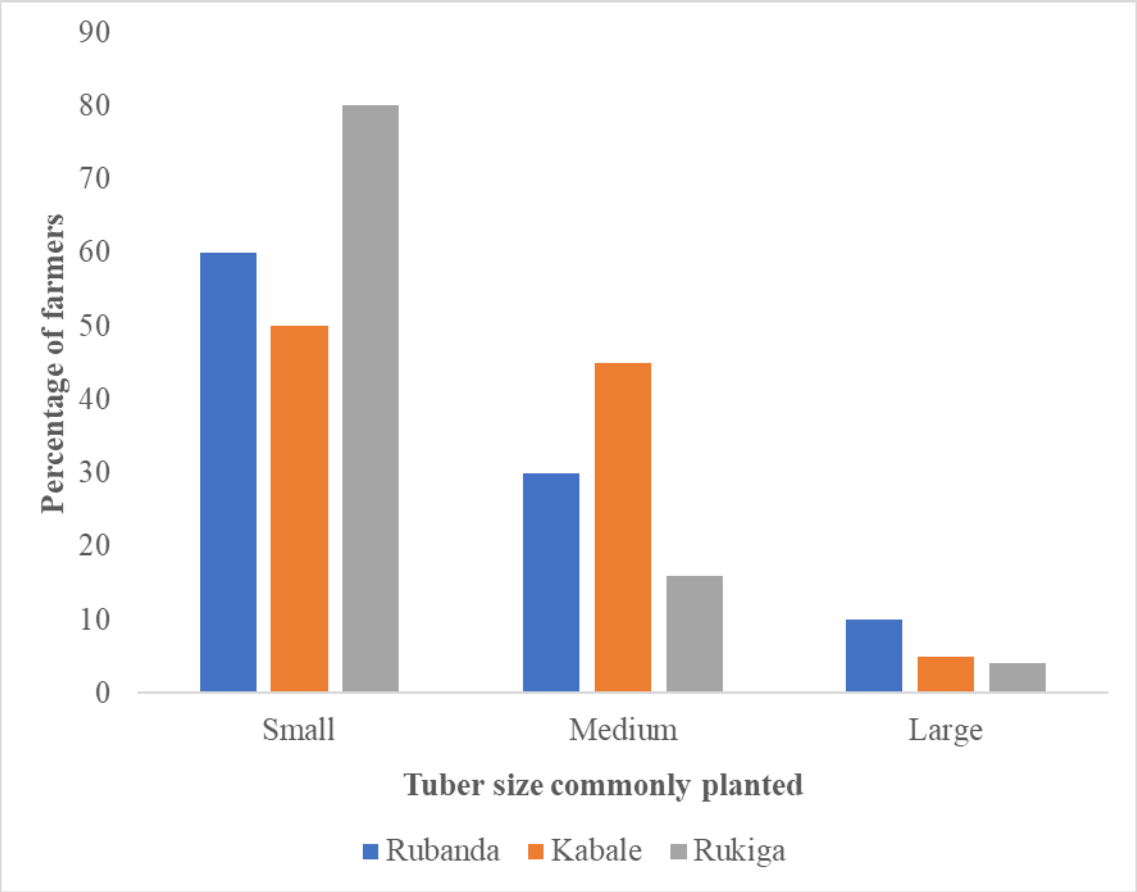

Figure 5: Size of potato tuber commonly planted by farmers who use recycled seed

Results from FGDs indicated that small tubers were the most used as potato planting material (60, 50 and 80%) in Rubanda, Kabale, and Rukiga districts respectively (Figure.5). After potato harvesting, farmers sort out large and medium tubers for sale to meet immediate basic needs like school fees and basic health and reserve small tubers which are then pilled in dark places to sprout for the next planting season.

> *"After harvesting, I remove tubers which relatively big and sell them to get money for fees and medication. I leave the small tubers which I can't peel to cook piled in one of the corners in the house to sprout and I use them as seed next season. Sometimes when there is nothing to cook in house, I can spare some time to peel some of them to supplement the main meal*" (A female farmer, FGD in Rukiga district)

Some of the smallholder farmers preferred using small size seed because it can plant comparably a bigger portion of the garden than medium and larger size.

> *"To me, I like planting small tubers because I can plant a larger area compared to medium-size or large size, hence I can plan for my garden well for the quantity I need, instead of going to other sources and finding no seed"* (A farmer in Kabale district during FGD).

This finding contradicts with existing literature where medium and large tubers recommended for high potato yield and productivity (Masarirambi *et al*., 2012). From a scientific point of view, the size of seed does not significantly affect potato yield when quality seed is used, but the reverse is true when recycled seed system is used (Mumia *et al*., 2018). According to the authors, recycled seed tends to undergo gene degeneration resulting from use over a long period and/or disease accumulation, thus losing its growth vigor.

The relationship between seed tuber size and potato yield has also been extensively studied by several authors such as Asnake *et al*. (2023) who categorized tubers into small (31.5 ± 2.5g), medium (57 ± 2.5g), and large (77.5 ± 2.5g). According to their research, the size of the seed tuber plays a pivotal role in determining the overall yield and productivity of the potato crop. The authors noted that smaller seed tubers are often characterized by a reduced number of eyes and limited food reserves, which are crucial for vegetative growth. Consequently, the use of small-sized tubers can lead to suboptimal plant development and smaller harvests. Proponents of using medium and larger seed tubers such as Asnake *et al*. (2023) argue that the increased number of eyes and greater food reserves facilitate better vegetative growth, resulting in higher yield. Medium and large-sized tubers enhance plant vigor and tuber size at harvest, leading to improved productivity. Larger tubers, with their more substantial nutrient reserves, can sustain the plant through critical growth stages, thereby optimizing yield potential. This finding points to the need for extension information to demonstrate the missed opportunities in dwelling in recycled potato seed. Thus, there is need for urgent and continuous extension services and training programs to create awareness to inform farmers on the benefits of transitioning from recycled seed systems and/or using medium and large size tubers as an innovative intensification potato practice.

3.2.2.1 Strategies used by smallholder farmers to maintain quality standards in recycled potato seed system

Findings from FGDs indicated that farmers employed both scientific and traditional methods to keep quality standards in cases where home saved potato seed was used (Figure 6). The main

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scientific method used was positive seed selection (PSS) and this was supplemented by potato tuber sorting and grading. Positive selection is an innovation where mother plants to serve as a sour of seed in the following season are selected from the best-looking potato plants still in the field before flowering time (Muthoni *et al*., 2022). The rest of farmers were scattered in more traditional methods such as soil preservation which was more common in Rukiga district and spraying with ash or ambush to control diseases related to rotting.

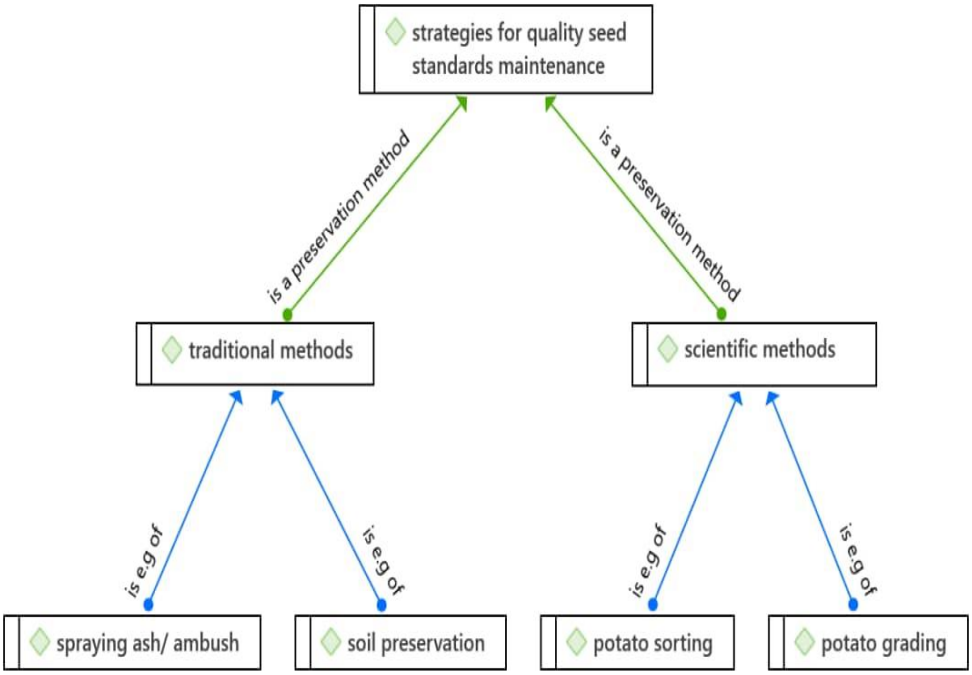

Figure 6: Strategies for maintaining quality standards in home-saved potato seed

Source: Field data

The practice involves informal identification and pegging of robust and healthy-looking plants during crop growth before flowering and just before crop senescence that obscures disease symptoms (Okeyo et al., 2018). The pegged plants are checked two weeks after and pegs are removed from the plants that exhibit disease symptoms (Muthoni et al., 2022). At maturity, the plants that ultimately remain pegged are subsequently harvested individually, ensuring that plants with few, small, or malformed tubers are disregarded (Okeyo et al., 2018). Ultimately, smallholder farmers should be enabled to access the knowledge and resources needed to integrate informal seed sources such as home saved seed sources with formal seed systems that enhance potato yield and productivity, economic sustainability, and resilience of potato production systems.

3.2.3 Potato-based intercropping systems used by smallholder farmers

Findings revealed that Sorghum and maize were the most crops intercropped with potato (60, 80 and 80%) for Rubanda, Kabale and Rukiga districts respectively (Table 2).

Table 2: Crops intercropped with potato

District	**Rubanda**	**Kabale**	**Rukiga**
Companion crop	**Percent of farmers**		
Sorghum	60	70	50
Sweet potato	20	30	20
Beans	50	40	70
Maize	50	80	80
Cabbage	30	10	30
Carrots	40	30	30
Bananas	30	10	30
Other vegetables	40	30	20

Source: Field data, 2018/2019

> *"When I intercrop potato with maize or sorghum, am not only assured of higher yield. Sometimes, at least am assured of some harvest in case one of the two crops fail due to bad weather*" (An elderly female farmer in Kabale district during FGD).

Potato intercropping is one innovations that improve crop yield and productivity per unit of land (Gitari *et al*., 2020; Maitra *et al*., 2021; Sharma & Banik, 2015; Weih *et al*., 2022; Yang *et al*., 2017). Previous authors including Campos & Ortiz (2019) argue that intercropping combinations, such as potato intercropped with onions, may offer unique advantages in terms of pest management. Related literature including Nakibuule *et al*. (2022) argues that potato-legume intercropping, specifically utilizing beans as a companion crop, should be prioritized over other intercropping combinations to enhance potato productivity and ecological sustainability. From economic and ecological standpoints, of potato-based intercropping systems consistently demonstrate that intercropping potato with legumes, such as beans leads to higher yields and improved soil fertility (Gitari *et al*., 2020; Nakibuule *et al*., 2022). Beans can fix atmospheric nitrogen, providing a natural source of fertilizer for potato and reducing the need for additional nitrogen inputs (Nakibuule *et al*., 2022). This not only enhances

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potato yields but also promotes ecological sustainability by minimizing the environmental impacts associated with synthetic fertilizers. Relatedly, the complementary growth habits of potato and bean crops enable efficient utilization of resources and space, resulting in enhanced land productivity and economic returns for farmers (Gitari *et al.*, 2020). Whereas potato-based intercropping combinations may offer significant benefits in terms of crop productivity and ecological sustainability under certain conditions, it is not a one-size-fits-all solution. Therefore, farmers and policymakers should carefully evaluate the potential advantages and limitations of different intercropping strategies based on local agroecological conditions, socioeconomic factors, and agricultural objectives. By adopting a holistic and adaptive approach to intercropping, farmers can harness full potential of diverse cropping systems that enhance food security, resilience, and sustainability in agricultural landscapes.

3.2.4 Soil fertility management practices by smallholder farmers

3.2.4.1 Use of synthetic fertilizers

The findings from the FGDs revealed that most of smallholder farmers in Rubanda, Kabale, and Rukiga districts (70 and 60% each respectively) were not applying inorganic fertilizers in potato gardens (Figure 7). Further, it was noted that some of the farmers applying inorganic fertilizers in Rukiga district (30%) could not ably describe the fertilizer they use by name.

> "*Last season, I used the fertilizer which looks like black stones and other one which looks like small pink granules"* (FGD in Rukiga district).

Upon further probing, it was noted that the described fertilizers were DAP and NPK respectively. It was also noted that other farmers applied fertilizers in a mixture. Such findings raise significant concerns about agricultural practices and sustainability in these regions.

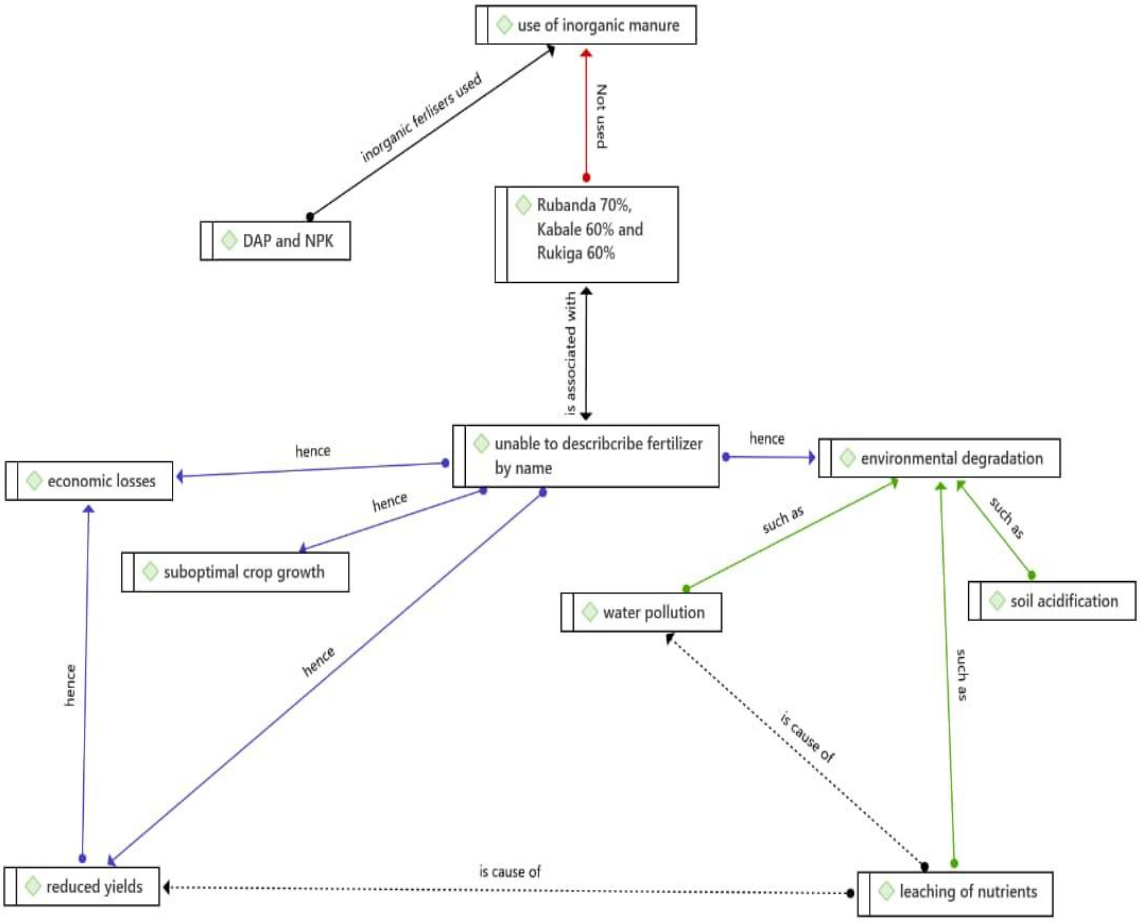

Figure 7. Use of synthetic fertilizers by smallholder farmers

Fertilizers are a cornerstone of modern agricultural practices, enhancing soil fertility and crop yield (Nakibuule *et al.*, 2022). Therefore, the inability of farmers to identify fertilizers they use raises critical issues touching on agricultural education, policy, and practical farming outcomes. For instance, it reveals a critical gap in agricultural knowledge and education (Diop *et al.*, 2022). Misidentification or improper application of fertilizers can lead to suboptimal crop growth, reduced yield, and economic losses. Additionally, inappropriate use of fertilizers can cause environmental degradation, such as soil acidification, nutrient runoff, and water pollution (Massah & Azadegan, 2016; Tripathi *et al.*, 2020). Therefore, fertilizer use should be an integral part of potato production.

3.2.4.2 Use of farmyard manure in potato production

Findings from FGDs revealed that majority of farmers from Rubanda, Kabale, and Rukiga districts (70 and 60% each respectively) did not apply organic fertilizers (Figure 8). Even the few farmers who applied organic fertilizers applied the manure by tethering livestock such as cows, goats, and sheep in the plot gazetted for potato production some months before growing potato such that the animals drop waste on the soil surface as the randomly graze.

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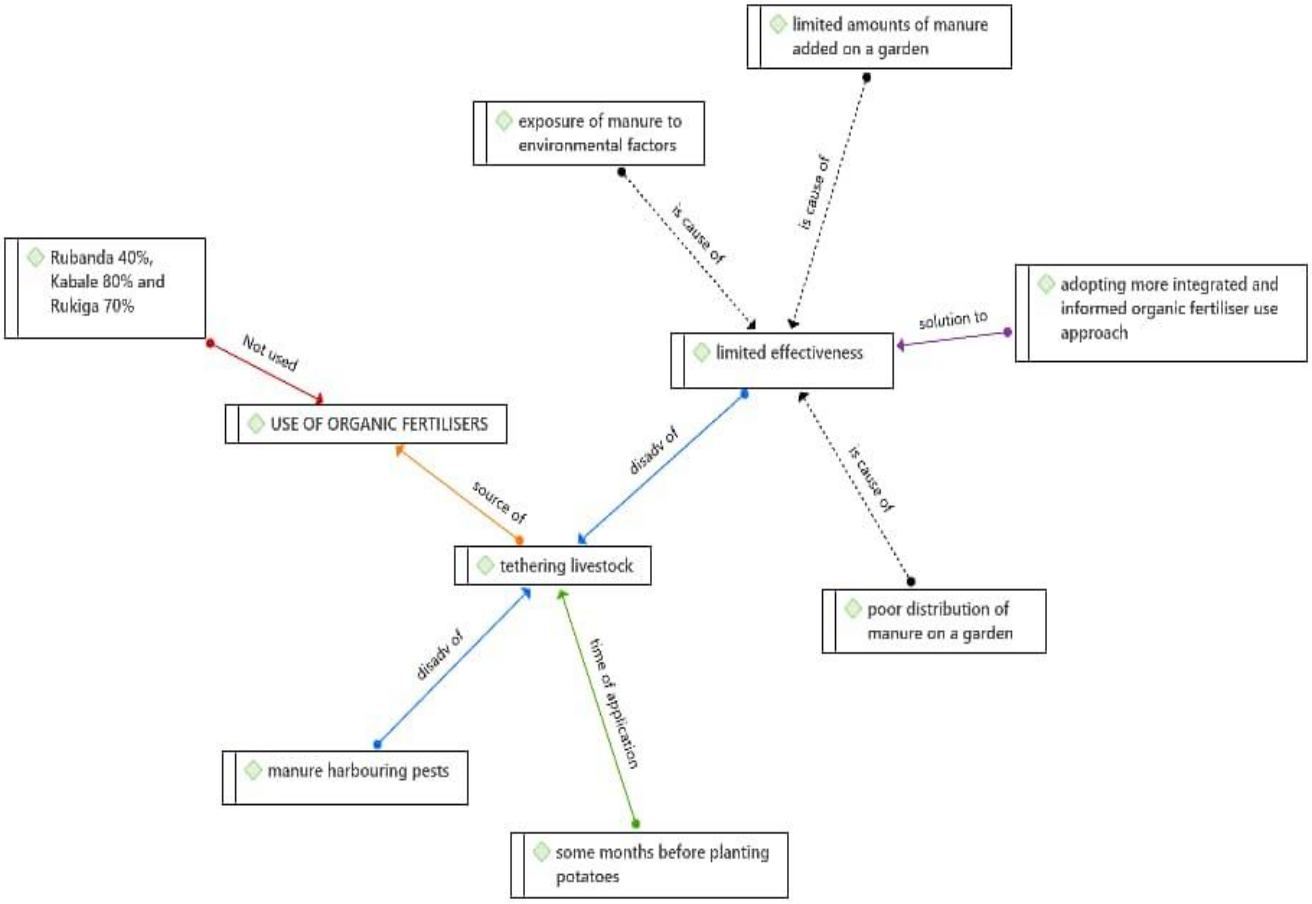

Figure 8. Use of Farmyard manure to maintain soil fertility by smallholder farmers

> "*When you use farmyard manure, you invite pests in your garden, especially 'kanyarugongo' (Thrips) which climbs up the potato shoot and feeds on the leaves at night"* (Elderly farmer during FGD in Kabale district).

With such beliefs among smallholder farmers in a situation where use of inorganic fertilizers is very limited, balancing soil fertility and issues related to a balanced ecological system such as climate change remains a challenge (Goldan *et al*., 2023; Jan *et al*., 2020). Using farmyard manure is a low-production cost innovation that ensures an environmentally friendly product that is key for the growth conditions of crops (Goldan *et al*., 2023). Farmyard manure has high potential to supply crop nutrients over a longer period of time than inorganic fertilizers (Jan *et al*., 2020). From a policy perspective, increased use of manure in agriculture has a positive impact on the environment (Hou *et al*., 2018).

Several studies including (Goldan *et al*., 2023; Jan *et al*., 2020) have highlighted the inefficiency of relying solely on organic fertilizers through grazing methods. The authors argue that nutrient contribution from farmyard manure, while beneficial, is insufficient for high-yielding crops without supplementation from other sources. They also emphasize the importance of proper manure management practices to maximize nutrient retention and distribution. Farmyard manure application by livestock grazing is inefficient because nutrients in the manure are lost by leaching or eroded by rain or by the process of volatilization due to much exposure to high-temperature (Wang *et al*., 2021). Therefore, while the practice of applying farmyard manure through livestock tethering has traditional and some economic merit, its sustainability and limited effectiveness. Addressing this limitation requires adopting a more integrated and informed approach to organic fertilizer use to achieve better crop yields and long-term soil health, contributing to more sustainable agricultural systems. Therefore, there is need for extension services to overturn the non-enterprising farmer perceptions towards use of farmyard manure not only as a cost-saving innovative practice but also environmentally friendly practice for enhanced potato yield and productivity and sustainable environment.

3.3 Resource use allocation in potato production

Resource allocation priorities in Southwestern Uganda underscore the complex interplay between economic needs, food security, and sustainable agricultural practices (Table 3).

Table 3. Resource use allocation in potato production

Resource prioritization in potato	**Rubanda**	**Kabale**	**Rukiga**
	Percent of farmers		
Land allocation	90	90	60
Labor allocation	90	80	60
Agro-input allocation (Fertilizer use)	50	40	30

Source: Field data, 2022

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3.3.1 Land allocation in potato production

In Rubanda, Kabale, and Rukiga districts, potato farming is a major agricultural activity, with 90, 90, and 60% of farmers respectively, prioritizing it in land allocation among household economic activities. Farmers prioritize potato due to its quick maturation as a crop, which provides quickest source of household food and income source.

> "*When you grow potato, you can't wait for long before you have food*" (FGD, Kabale district).

Potato crop prioritization among household farmers has significant implications for agricultural productivity on household food security, and economic stability in the region. Proponents argue that prioritizing potato cultivation offers substantial economic and nutritional benefits (Kajunju *et al*., 2021; Sebatta, *et al.*, 2015). Potato matures faster than many other crops, enabling farmers to harvest and sell their produce more quickly, thus generating faster income than many other crops (Campos & Ortiz, 2019; Jennings *et al*., 2020; Singh *et al*., 2016; Zaheer & Akhtar, 2016). Also, potato is a crucial source of food, rich in carbohydrates and essential nutrients, which can help improve food security and nutritional status among farming communities (Campos & Ortiz, 2019). Furthermore, potato has a short growing season which allows multiple cropping cycles within a year, potentially increasing overall agricultural productivity (Namugga *et al*., 2018). This rapid turnover has economic benefits particularly, in regions with limited arable land as it maximizes the use of available land resources.

3.3.2 Labour allocation by smallholder farmers in potato production

In the districts of Rubanda, Kabale, and Rukiga in Southwestern Uganda, a significant portion of labour (both family and hired) compared to other crops (90, 80 and 60% respectively) (Table 3).

> *"Potato is my main source of food and income; I have to give it attention first before thinking about other crops*" (Farmer, Rukiga district).

This substantial labour investment in potato farming reflects the crop's importance in these regions. This concentration of labour resources raises several critical issues related to economic efficiency, labour dynamics, and sustainable agricultural practices. Proponents argue that allocating a large portion of labour to potato farming is justified given the economic importance of the crop. Potato provide quick financial returns due to their relatively short growth cycle, enabling multiple harvests per year and consistent cash flow for farmers (Degebasa, 2019). This rapid turnover is critical for smallholder farmers who depend on immediate income to meet their daily basic needs and reinvestment into agricultural activities. By dedicating substantial labour to potato cultivation, farmers ensure a steady supply of this vital food source, thereby enhancing household food security and nutritional status (Campos & Ortiz, 2019; Mugisha *et al.*, 2017; Nassanga *et al.*, 2018; Zaheer & Akhtar, 2016). High labour allocation to potato farming also has positive social implications, particularly in terms of employment (Degebasa, 2019).

3.3.3 Agro-input allocation in potato production by smallholder farmers

Findings from focus group discussions (FGDs) from Rubanda, Kabale, and Rukiga districts indicate that potato farming, though significant, was not prioritized regarding agro-input purchasing (50, 40, and 30% respectively) (Table 3).

> *"We stopped using fertilizers and manure in potato because of diseases. You can end up losing everything*" (FGD, Kabale district)

Low prioritization in agro-input allocation into potato production, particularly fertilizers, results in soil nutrient depletion over time (Haverkort *et al*., 2012). Potato is a nutrient-intensive crop, which means that soil fertility must be maintained for sustainable production. Therefore, prioritizing agro-input allocation into its production could enhance its yield and productivity, thus, improving food security, and boosting economic returns.

By increasing the priority of potato in agro-input distribution, farmers can maintain soil health and ensure long-term productivity. Relatedly, there is a growing market demand for potato, both domestically and internationally (Sebatta, *et al.*, 2015; Wijesinha-Bettoni & Mouillé, 2019). Allocating more inputs to potato production can help farmers meet this demand, ensuring a stable supply chain. Enhanced input use, particularly fertilizers, can improve potato quality, making it more competitive in the market (Devaux *et al*., 2021). The general low use of external agro-inputs, particularly inorganic fertilizers, in Rubanda, Kabale, and Rukiga districts has several implications. For instance, low input use directly correlates with lower crop yields (Nakibuule *et al*., 2022), hence reducing the profitability of potato farming. This not only limits the economic opportunities for farmers but also hinders rural development. Also, potato is sensitive to climatic change (Abdrabbo *et al*., 2010; Raymundo *et al*., 2018). Therefore, adequate input use, including fertilizers, can enhance its resilience to adverse weather conditions (Jennings *et al*., 2020).

3.4 Potato prioritization and utilization by smallholder farmers

3.4.1 Potato prioritization as food crop

It was indicated from FGD findings that potato was considered the major source of household food (70, 60, and 80%) for Rubanda, Kabale, and Rukiga districts respectively (Figure 9).

"*Potato can give you food very fast and your children can get what to eat in a short time*" (A farmer in Rubanda during FGD).

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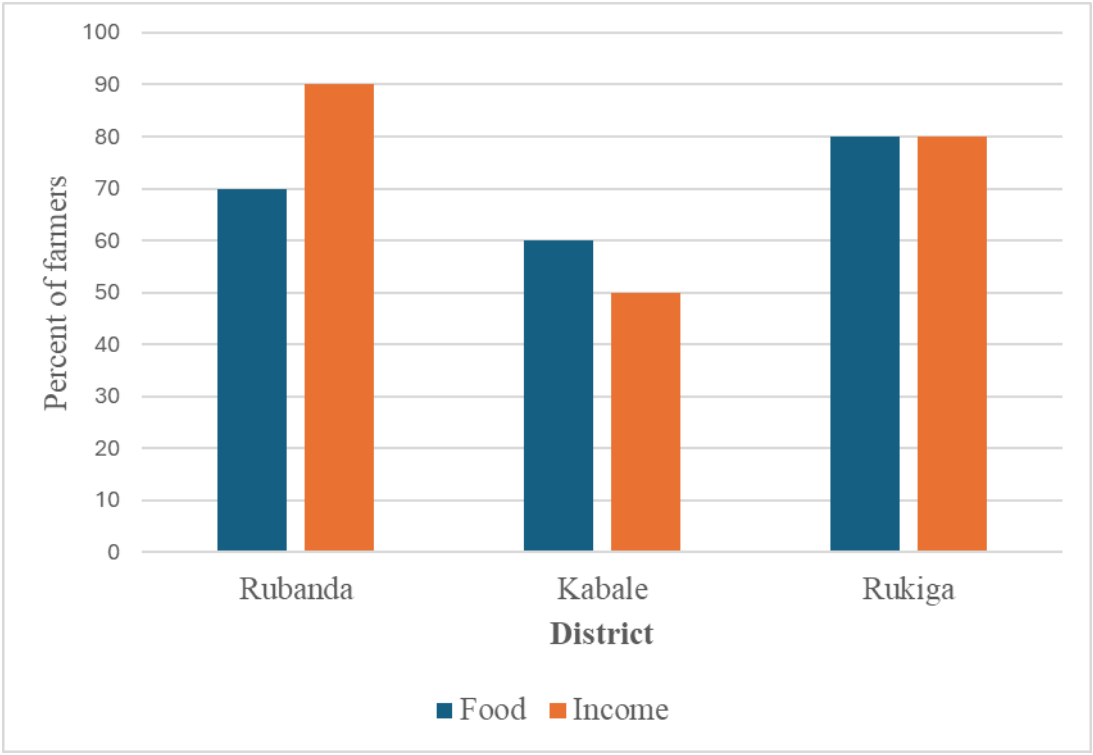

Figure 9. Potato utilization among smallholder farmers

Source: Field data, 2022

Potato is also a staple food in the region, contributing significantly to food security *(*Aheisibwe *et al*., 2015; Kajunju *et al*., 2021; Sebatta *et al*., 2014; Sebatta, *et al*., 2015). It is rich in carbohydrates and essential nutrients, making it a crucial component of the local diet (Campos & Ortiz, 2019).

3.4.2 Potato as a source of household income

Potato was considered a major source of income by most farmers (90 and 80%) in Rubanda and Rukiga districts respectively) compared to Kabale district (Figure 9). This finding could be explained by the nearness of the farmers to Kabale town which paves ways for other opportunities such as trade and commerce as an alternative income source for most farmers. In the districts of Rubanda and Rukiga, potato is a primary source of income (90 and 80% respectively). In contrast, Kabale district shows a comparable lower dependency (50%) on potato farming, likely due to its proximity to Kabale town, which provides additional economic opportunities in trade and commerce. This disparity invites a critical examination of the economic implications of reliance on a single crop versus the benefits of diversified income sources. Potato farming emphasizes its role in providing immediate and stable income due to the short growing cycle, allowing for multiple harvests each year, which ensures a steady cash flow (Degebasa, 2019; Haverkort & Struik, 2015). Regular income is crucial for smallholder farmers, who rely on frequent revenue to sustain their households and reinvest in their farming operations. The consistent demand for potato-based products in local and urban markets guarantees that farmers can sell their produce at profitable prices, further solidifying potato as a reliable income source (Kajunju *et al*., 2021).

Potato is a staple food with high market demand, ensuring farmers with a reliable market for their produce. Additionally, their nutritional value contributes to local food security, making them an essential crop for both economic and social reasons (Kajunju *et al*., 2021; Kyomugisha *et al*., 2018; Sebatta *et al*., 2015). The high carbohydrate content and essential nutrients provided by potato support the nutritional needs of the farming communities, reducing malnutrition and enhancing overall health (Sebatta *et al*., 2015). Finally, potato farming is labour-intensive, creating significant employment opportunities in rural areas (Degebasa, 2019). This labour demand is particularly vital in regions where alternative employment options are limited. Therefore, by engaging in potato farming, rural households can secure livelihoods, reduce poverty and enhance economic stability.

3.5 Main challenges encountered during potato production

Findings from FGDs revealed that there were four major challenges predominantly impacting different categories of smallholder farmers: limited knowledge, limited access to improved seed, limited labour, and pests and diseases. Each challenge affects farmers differently based on their adoption of various agricultural practices (Table 4).

Table 4. Main challenges encountered by smallholder farmers practicing different potato production practices

	Major challenge by percentage of farmers			
Farming practice used	**Limited labour**	**Pests& diseases**	**Limited access to seed**	**Limited knowledge**
Traditional practices		90		
Improved seed			90	
Potato-bean intercrop	90			
Fertilizers & FYM				80
				90

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Recommended spacing				
Complete package				90

Source: Field data, 2022

Limited knowledge (90, 80, and 90%, respectively) emerged as a critical barrier, particularly affecting farmers using recommended spacing, those practicing soil fertility management, and those employing a combination of practices. Lack of knowledge can severely limit the effectiveness of advanced agricultural techniques. Scientifically, the role of agricultural extension services is crucial in disseminating information and best practices (Beshir, 2014; Chimoita *et al*., 2019; Dernat *et al*., 2022; Kabir & Rainis, 2015; Maulu *et al*., 2021; Norton & Alwang, 2020; Ntshangase *et al.*, 2018). However, with adequate information and understanding of new practices, farmers are likely to implement them effectively. Scholars argue that addressing the knowledge gap through extension services, farmer training programs, and demonstration plots significantly enhances innovation uptake. When farmers see tangible benefits and receive hands-on training, their confidence in new practices increases, leading to higher adoption rates. Other scholars including Makate (2019); Nyumba *et al*. (2018) argue that even with knowledge, farmers may be hesitant to adopt innovations due to ingrained traditional practices and skepticism about new practices. Also, mere knowledge transfer might not be adequate if it is not accompanied by practical support and continuous guidance. Literature indicates that well-structured training and capacity-building programs significantly improve farmers' understanding and application of advanced techniques, thereby enhancing productivity (Alawa *et al*., 2020; Ankrah & Freeman, 2022; Norton & Alwang, 2020). As such, addressing this challenge requires robust extension services that are accessible and tailored to the needs of different farmer categories.

Also, limited access to improved seed was another major challenge (90%), limited labour (90%) mainly affecting farmers adopting potato-bean intercropping system, and pests and diseases (90%) mainly affecting farmers scattered in traditional potato production practices.

Improving access to quality seeds involves enhancing seed distribution systems, subsidizing costs, and ensuring that improved seeds are adapted to local conditions. Studies have shown that farmers with better access to quality seeds experience higher yields and more consistent production (Muthoni *et al*., 2022). However, even with improved access to high-quality seed, farmers may be reluctant to switch to new seed varieties due to concerns about seed dependency, loss of traditional varieties, and the risk of crop failure if new seeds do not perform as expected in local conditions (Makate, 2019).

In agriculture production, shortage of labour is usually due to aging farming populations and the labour-intensive nature of certain agricultural practices. Tackling labour shortage requires a multifaceted approach, such as promoting labour-saving innovations, including mechanization and improved tools and equipment, and enhancing rural livelihoods to retain the youths in farming (Alomia-Hinojosa *et al*., 2018; Beshir, 2014; Gatto *et al*., 2020; Kansiime *et al*., 2021). Similarly, integrating innovation to reduce labour demands can increase efficiency and reduce the physical burden on farmers. Therefore, innovations that require more labour than traditional methods may be less attractive to farmers, particularly in regions facing labour shortages due to demographic changes, thus, innovations that increase efficiency and reduce labour requirements can make adoption more feasible and attractive. Similarly, the cultural attachment to traditional farming practices and concerns about the reliability of new practices may hinder adoption.

Finally, traditional farming practices are scientifically synonymous with pests, and diseases due to rudimentary meanly applied by farmers most of which lack scientific basis (Birch *et al*., 2012; Mumia *et al*., 2018; Tadele, 2017). The changing climate exacerbates this issue by altering pest and disease dynamics (Peace, 2020; Skendžić *et al*., 2021). Therefore, integrating modern pest management strategies such as Integrated Pest Management (IPM), with traditional knowledge offers better and sustainable solutions. As traditional practices may emphasize the use of concoctions from diverse herbs and plant species, IPM emphasizes the use of biological controls, resistant crop varieties, and judicious use of pesticides, aligning with ecological principles and ensuring long-term sustainability (Baker *et al.*, 2020; Bueno *et al*., 2021; Deguine *et al*., 2021). However, the complexity and cost of implementing pest control innovations can be less attractive for smallholder farmers.

4 CONCLUSIONS AND RECOMMENDATIONS

Disparity between actual and potential potato yield is still persistent in Southwestern Uganda. This is attributed to traditional practices used by farmers, notably the reliance on low-cost, readily available recycled seed potato which are associated with genetic degeneration and disease accumulation, though economically convenient. Recent experimental studies indicate that utilization of high-quality seed, adequate soil fertility enhancement practices, and suitable companion cropping strategies can close this yield gap. The aim of this study was therefore to highlight the practical and theoretical implications of smallholder farmers' practices in potato farming system in the districts of Rubanda, Kabale, and Rukiga. Qualitative data were gathered through focus group discussions (FGDs) with participants purposefully selected based on their active involvement in various aspects of the interventions by CARP+ potato crop intensification innovations. Data was analyzed using a combination of thematic analysis using ATLAS.ti software and descriptive statistics. Results indicated that home-saved potato seed source was the most used because it was perceived as cheap, guaranteed seed availability, self-reliance and acted as source of food and income during emergencies. Conversely, in addition to being associated with non-uniform seed size and seed of mixed varieties, research stations such as Kachwekano-ZARDI potato seed source were not only perceived to be more expensive, but also smallholders thought that it deals with rich farmers and registered groups. Maize and sorghum were the main potato-based intercrops. Farmers also inadequately applied farmyard manure and inorganic fertilizers but also not differentiate between inorganic fertilizers being used in potato production due to limited information. Based on such findings, the study recommended integrated extension programs that provide comprehensive training on quality seed, soil fertility management, and sustainable farming practices. The study also highlights a need to develop regulatory frameworks that support the integration of informal and formal practices particularly the seed systems to

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leverage on strengths of both formal and informal potato seed systems.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

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