Making Potato Value Chain Enhance Productivity and Incomes in Uganda




RUFORUM POTATO CARP^{+}: Grant No. RU/2018/CARP+/02

END OF PROJECT REPORT

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Executive Summary

In Uganda, potato has increasingly become a food and cash crop but its productivity has stagnated below 7.5t/ha compared to its potential (20t/ha) due to many factors. The main ones are limited access to quality seed, scarcity of other farm resources especially land and capital inputs, and limited value addition. Farmers have a narrow choice of market outlets which impacts on productivity and profitability of the crop.

This 4-year CARP+ Project with a budget of USD350,000 focused on the seed potato value chain, crop-intensification production, value addition, and market linkages to provide appropriate interventions. The interventions were possible solutions on how best seed potato can be made more available and accessible by farmers, how potato farmers can practice a sustainable crop intensification production that maximises the benefits, and how the value of potato can be improved through processing and marketing for increased benefits to farmers and consumers.

The project, therefore, targeted ware and seed potato producers, potato growers' associations, processors, researchers and consumers. It partnered with the private and community-based organisations, Research Institutions and TVET Institution that trains Mid-Level Cadres in Uganda in areas of agriculture, agribusiness and human nutrition.

The overall objective of the Project was to enhance the capacity of potato value chain actors to reduce the challenges that constrain sustainable potato productivity. The specific objectives were to (i) test and demonstrate a community-based model for farmers to participate in production, delivery and use of quality seed potato; (ii) test and validate a system of potato intensification that optimises farmers' resources whilst increasing productivity; (iii) develop and test potato-based value added products; (iv) determine market potential of the potato valued added products and promote market linkages for the products; and (v) support human resource development for research and sustainable development of agricultural value chains. The Project was based on hypotheses that (1) availing quality and quantity seed potato to farmers at affordable cost, (2) optimising intensified production system of potato and other crops, (3) providing alternative markets for potato through value addition will increase potato productivity and profitability thus increased incomes in the potato growing areas of Uganda.

The project team constituted staff and organisations with multidisciplinary backgrounds and relevant experiences. The team included academia and researchers at University, Research and Extension organisations, Community-Based Organisation, a potato processing and business incubator, graduate and undergraduate students, a private sector, and TVET Instructors and students.

This Project used methodologies that enabled potato value chain actors especially farmers to actively participate in the research processes. This was to enable the Project to come up with "farmer-developed and owned" alternative interventions for the value chain actors to choose from, which expectedly accelerates the adoption of the chosen alternatives. To establish a functional community-based system for farmers to participate in production, delivery and use of quality seed potato, Potato-based Innovation Platforms were formed. The Platforms identified cost-effective technologies and practices that produce quality seed; building on current knowledge and practices by the farmers who have been preserving their own seed and potato growers' associations that have been producing foundation seed.

In addition, Farmer Field Demonstrations were established to validate a system of potato intensification that optimises farmers' resources. The demonstrations were farmer-managed with the research team playing a guiding role.

The Project also developed and tested potato-based value added products to widen potato market outlets, increase incomes of producers and expand consumer choices. The viable prototypes were further developed and promoted for commercialisation. In implementing the project, capacity building was done among the targeted value chain actors and students at the University and TVET Institution.

From the project interventions, farmer who adopted the use of quality seed and recommended crop intensification practices have realised increased potato productivity; yield of up to 10t/ha compared to the current 4.2t/ha, and increase in yield of 138%. There is increased availability and accessibility of quality seed, and reduced costs of production per unit area. There are 3 farmer groups (93 farmers) producing quality seed and selling to other farmers.

The value of the tiny potato tubers originally non-marketable has increased through processing them into flour, cookies, and other high value products; with a 12-15% increase in the value of potato tubers.

Throughout the project period, the Project worked with 3 farmer groups, and about 1,730 farmers were trained. Among the 700 farmers who participated in the Farmer Field Demonstrations, over 70% were willing to use the recommended practices. They realise increased land, capital and labour use efficiency, and increased yields for potato and other crops.

As regards developing and testing marketable potato-based value added products, 7 potato value addition protocols (for flour, French fries, cookies/biscuits, cakes, waffles, chapatti, daddies) were developed. Four potato-based products (cookies/biscuits, cakes, waffles, daddies) were developed and market tested, and two potato-based businesses (Applied Agribusiness Innovations and Muhingi Products Ltd) were incubated. These have taken up some of the products to the market, hence an increased number and sales of marketable potato-based products, and increased incomes of potato value chain actors.

In addition to the farmers, farmer groups and entrepreneurs, the capacity of TVET and University students was built. The Project trained 93 TVET students of Bukalasa Agricultural College, and 4 BSc interns, 6 MSc students and 1 PhD student of Makerere University. As such the capacity of farmers to increase productivity, entrepreneurs to produce value-added products, and students/graduates to serve communities in agricultural value chains was enhanced.

The Project concluded that the potato crop value chain in Uganda can be enhanced for improved livelihoods of the farming communities and other value chain actors through multidisciplinary participatory approaches. An improved seed value chain that enables the farmers to access quality seed and empowers them in seed selection and handling impacts on crop productivity and profitability. Furthermore, adoption of optimal crop intensification practices impacts positively on the quality and yield of crop harvests, hence increasing the use efficiency of the scarce farm resources.

Moreover, production of high value processed products is feasible and economically viable. The processed products have attributes that are acceptable by the market, and commercialisation of the products will create backward linkages in the value chain that will impact positively on farmers' productivity and incomes.

In order to achieve a greater and sustainable impact, projects with longer time and bigger budgets to allow, try and accommodate ideas and innovations that emerge in the process of project implementation should be designed and implemented. Besides, the results that have been achieved by this Project need upscaling; others need follow up and monitoring.

1. Introduction

1.1 Background

Potato (*Solanum tuberosum* L.) is ranked the third world's most important tuber crop grown by small scale farmers for both cash and food (Muthoni *et al*., 2013). In sub-Saharan Africa, production of the crop has more than doubled since 1994 with about 70% of the growth concentrated in Eastern Africa (Lutaladio *et al*., 2010). In Uganda, its production is concentrated in the highland areas. The South-western highlands of Kabale and Kisoro produce about 60% of total output (FAO, 2008), while the South-eastern mainly in Mbale and Kapchorwa contribute about 10%. The increasing demand for potato especially among urban dwellers has led to production expansion to the non-traditional growing (lowland) areas of Uganda (Ferris *et al*., 2001) including Isingiro, Rakai, Lyantonde, Mubende and Mityana. Recognizing the increasing importance of potato, the International Year of the Potato encouraged policy makers, agronomists and economists to re-evaluate the potato in its role as an ideal crop to sustain food security through crisis (FAO, 2010). Furthermore, emerging initiatives and technologies, such as production of mini-tubers and quality-declared seed (QDS) require additional supportive policies for recognition and regulation in production and distribution. The FAO therefore recommended that the major potato growing countries should have a seed policy guide and regulations that addresses the issues of seed potato in order to promote a well- co-ordinated and functional potato value chain. To address these policy issues, the government of Uganda, under the National Development Plan II (2015-2020) has developed a Potato Framework Implementation Plan (FIP) which, among others, focuses on supporting production, distribution and marketing of seed and ware potato, and provision of an enabling policy framework.

1.2 Project context

Many studies have attributed the declining productivity of potato to limited availability and use of quality seed (Okello *et al*., 2017; Karanja *et al*., 2014; Janssens *et al*., 2013). Gildemacher (2009) reported that clean seed potato if available is expensive because of a wide seed supply-demand gap. As a result, farmers use recycled seed from the previous seasons. Gildemacher *et al*. (2007) reported accumulation of seed borne diseases in the farm-saved seed used for several cropping resulting into degeneration and poor yields.

In addition to using poor quality seed by most potato farmers, low adoption of other innovation inputs and practices (Wang'ombe and van Dijk, 2013) and inefficiency in the use of existing farm resources (Kemigisha, 2017) has lowered farm yields far below the potential. A set of principles and practices, collectively referred to as systems of crop intensification (SCI), that improve the productivity and resilience of crops, have become popular globally (Adhikari *et al.,* 2018). SCI methods are of great relevance for resources-poor and nutritionally vulnerable households because SCI does not rely heavily on purchased inputs. The major merit of SCI is its ability to enable crops buffer the effects of drought, storm damage, extreme temperatures, pests and diseases on both large and small farms. The six elements of SCI include starting with high quality seeds, optimal plant spacing to minimise competition, well-aerated top soil around the plant, avoiding water-logging, application of organic matter, and reducing reliance on inorganic fertilizers and pesticides. SCI has been adopted in several crops with noticeable improvement on crop performance (Adhikari *et al*., 2018), however, no attempt has been made to develop and test such a system on potato productivity in Uganda. Competition for the scarce resources with other crop enterprises has also been reported as a challenge (Kyanjo, 2017; Kazooba, 2007) especially where farmers lack adequate knowledge on how to optimally combine the resources. Broader integrative adaptation approaches such as intercropping has been shown to have several advantages over monocropping systems (Jalilian *et al*., 2017).

Intercropping potato with other crops, as one form of crop intensification, have produced mixed results, attributed to differences in location, available inputs, the crops intercropped and how they are intercropped. For example, Farooq *et al*. (1996) found that intercropping of beans, maize and potato gave lower yields and returns than potato alone. Similarly, in a potato-maize intercrop study in Central Uganda, Ebwongu *et al*. (2001) observed the highest yield in the sole crop followed by the 2:1 and 2:2 potato : maize mixtures. On the contrary, Kidane *et al*. (2017) observed greater total yield of intercropped crops (potato and maize) than sole cropping, with overall advantage of intercropping ranging from 35 to 58%. Similarly, One Acre Fund (2016) reported greater total yield in maize-potato intercrop at 1:1 maize: potato mixture in Rwanda, and with higher farmer preference for the intercrop than the monocrops. Manorama and Lal (2010) reported that intercrops of French bean-potato at 50:75 mixture was more productive than the sole crops, and better than maize-potato or wheat-potato intercrops. Van

Campenhout (2016) also observed that potato farmers in Uganda that practiced crop intensification got higher yields and profits. The author, however, noted that farmers perceive the intensification technologies as risky and adoption would depend on how well they can manage the associated risks.

Other challenges in the potato value chain have been reported at harvest and postharvest levels. Kiaya (2014) reported poor harvesting techniques, storage facilities, packaging and marketing systems as some of the main causes of postharvest losses in low developed countries. Some of these can be avoided or minimized, which is one of the aims of this proposed project. Misener *et al*. (1989) identified mechanical injury as the most significant parameter affecting the marketability of potato. Kyomugisha *et al*. (2017) reported limited value addition to potato as a barrier to increase production. Sebatta *et al*. (2015) reported that value addition to both ware and seed potato was profitable, with farmers adding value earning 40% more than those who did not. They recommended provision of the special skills in value addition. Janssens *et al*. (2013) recommended experimental farms and trials and farmer training as some of the solutions to empower farmers; an approach this project intends to adopt.

In Uganda, potato has become a staple in the diets of many households. The crop matures within 3-4 months and in some areas it is grown up to three times a year. This makes it a good pathway for enhancing household incomes and food security especially among low resource endowed households. However, potato productivity has stagnated below potential due to a multitude of factors. For instance, smallholder farmers in Uganda continue to obtain very low yield estimated at 7.5t/ha compared to 20t/ha that is reportedly achievable on research station (Byarugaba *et al*., 2017). The potato value chain is characterized by, among others, limited access to seed and use of poor quality seed (Aheisibwe *et al*., 2015). Most Ugandan potato producers do not benefit from quality seed due to limited production and distribution of quality seed from the formal seed system (Aheisibwe *et al*., 2015). Therefore, a community-based seed system is a short term alternative that can increase availability, accessibility and affordability of quality seed as option for formal seed system. Additionally, scarcity of other farm resources especially land also poses a challenge. In the main potato growing areas, arable land is very small yet farmers grow a wide range of crops which compete for the land. In such a situation, it becomes crucial to improve land use efficiency through intensification. However, most research on potato in Uganda has looked at the crop as though it is only grown as a monocrop and in isolation of other crops, yet in reality many farmers intercrop potato with other crops. This implies that the research has not benefited those farmers, partly explaining why adoption of some research recommendations has remained low (Mwanja *et al*., 2016). As such, combined experimental and modelling research becomes important to develop an optimised and sustainable cropping system under a range of agro-ecological conditions, biophysical production capacity and socio-economic factors.

According to KAZARDI Food Security Situation Analysis Report of 2017, 9% of farming households in Kigezi sub region were noted to be food secure, yet potato as a crop has the potential of enhancing food and nutrition security. This indicates that the full potential of the potato crop has not been fully exploited. This is attributed to limited market outlets lack of appropriate postharvest handling and value addition technologies that force the farmers to sell before or immediately after harvest (Sebatta *et al*., 2014) to avoid the high postharvest losses associated with the perishable crop. The sale of potatoes at low prices exerts pressure on the family food basket since the money obtained will not buy enough food (Mugisha *et al*., 2017). The other challenge is associated with limited value addition, implying that farmers have a narrow choice of market outlets which impacts on the profitability and competitiveness of the crop. There is thus need for integrated approaches to help these communities work and use potato towards achieving Sustainable Development Goals (SDGs).

The CARP+ Project titled, "Making Potato Value Chain Enhance Productivity and Incomes in Uganda" was conceived to contribute to solving these challenges in the potato value chain. It was a 4-year project (March 2018 – February 2022) with a budget of USD350,000. However, due to COVID-19 pandemic that paralysed most of the project activities, RUFORUM Secretariat gave a no-cost extension of one year.

This Project focused on (i) the seed potato value chain, (ii) crop- intensification production system, (iii) postharvest handling and value addition, and (iv) market linkages to reduce market inefficiencies and increase access to markets by providing appropriate interventions. The interventions were to provide solutions on how best quality seed potato could be made more available and accessible by farmers, how potato farmers could practice a sustainable crop intensification production that maximises the benefits (productivity, food and income) from potato and the other crops given the limited farm resources, how best farmers could handle potato after harvest to maximise returns, and how the value of potato could be improved through processing and marketing for increased benefits to farmers and consumers. The various interventions were gender-sensitive considering the roles played by men, women and youth in the potato value chain (Mugisha *et al*., 2017). This way the Project contributed to the First, Second, Third and Twelfth SDG goals through reduced hunger, poverty, and improved wellbeing of the people through good nutrition and increased responsible production and consumption.

The Project targeted farmers (for both ware and seed potato), farmer groups, processors, researchers, and consumers. By its design, strengthened the synergies and working relationships of the University, Community Based Organisations and Associations, Research Institutions and an Agricultural College that trains Mid-Level Cadres in Uganda in areas of agriculture, agribusiness and human nutrition, in their respective community outreach agenda.

1.3 Associated projects

There have been five research studies on potato done by the Principal Investigator at Makerere University. Two of them were funded by RUFORUM namely; "Enhancing Competitiveness of Potato Production in Lowland Areas of Uganda (2014-2016)" and "Enhancing Potato Production and Market Access in Uganda (2011-2012)". One, titled "Nutritionalization of the Potato Value Chain among Smallholder Farmers in South-western Uganda (2015-2016)" was funded by USAID Self Help Africa, and the other two; "Effectiveness and Efficiency of Extension Approaches in Promoting Dissemination and Adoption of Improved Potato Technologies in the Highlands of South-western and Eastern Uganda (2001-2003)" and "Resource Use Efficiency and Product Utilisation among the Potato and Sweet Potato Producers in Uganda (2001-2003)" were funded by the Rockefeller Foundation. Each project was developed and implemented building on the gaps identified and lessons learnt from the preceding ones, hence a rich literature and strong foundation for this proposed project.

There have been other related projects/programs which have generated knowledge useful in to this proposed project. For instance, the Uganda Food Security Initiative Project by Africare (2002-2006) in Kigezi region (Kabale, Kisoro, Kanungu and Rukungiri) to increase the quantity of food produced and reduce postharvest losses, among others, mainly targeted the potato value chain and development of related infrastructure. The Community Connector project by USAID, in partnership with Uganda National Seed Potato Producers Association (UNSPPA), has been focusing on developing the potato value chain to improve incomes of farmers in Kanungu, Kisoro and Kabale. In addition, NARO-Kachwekano Zonal Agricultural and Research and Development Institute (KAZARDI) and CIP have decentralised seed system approaches by collaborating with seed-producing organisations. The Food and Agriculture Organisation (FAO) assisted farmers in Kabale and Kisoro in potato production and postharvest handling technologies under the project titled "Strengthening Linkages between Small Actors and Buyers in the Roots and Tubers sector in Africa". A project on quality seed potato, which was funded by ASARECA and based on the identification of viable regional seed systems as one of the undertakings of ASARECA's Staple Crops Programme, was completed in August 2011. The project demonstrated an effective way of overcoming the shortage of clean seed potato among small scale farmers through the seed-plot technology and positive seed selection. There has also been an Incubation Program by the Uganda Industrial Research Institute (UIRI) in Kabale focusing on potato value addition (processing) and related activities. Excel Hort Consult Ltd (EHC) has also been promoting potato value chain and market linkages in South-western Uganda. Almost all the above projects/ programs have used a community-based approach which this project borrowed.

1.4 Project objectives and Theory of Change

The overall objective of the potato CARP+ Project was to enhance sustainable potato productivity through reducing the challenges that constrain the capacity of potato value chain actors in Uganda. The specific objectives were:

1. To test and demonstrate a community-based system/model for farmers to participate in the production, delivery and use of good quality seed potato.

2. To test and validate a system of potato intensification (SPI) that optimises farmers' resources whilst increasing productivity in South-western Uganda.

3. To develop and test innovative potato-based value added products with potential for commercialisation

4. To determine market potential and profitability of the potato value added products and promote market linkages for potatoes and the potato products.

5. To support human resource development for research and sustainable development of agricultural value chains.

The Project hypothesised that (1) availing quality and adequate quantity seed potato to farmers, (2) optimising an intensified production system of potato and other crops, (3) providing alternative value addition processes and markets to potato, would increase potato productivity and profitability thus resulting into increased incomes in the potato growing areas of South-western Uganda. Specifically,

i. using a community-based seed system, in addition to the formal system, increases availability of potato seed at a financially viable cost. Because potato production is profitable and farmers are rational, if seed is available and accessible in adequate amounts and at prices that make it profitable to use, farmers will participate more in production of the crop either by intensification or expanding the acreage. New farmers also get attracted in the value chain.

ii. Optimising crop intensification through use of quality seed potato and other input enhancing practices increases resource use efficiency and yields of both potato and other crops that tend to compete for the farm resources (Getachew *et al*., 2006). Benefits of adopting crop intensification are expected to be higher in areas where arable land is more scarce.

iii. Value addition and provision of alternative value addition processes and markets increases the demand for potatoes, which in turn increases participation by farmers, processors, traders and consumers in the potato value chain, and a backward pull on productivity.

2. Research approach and conceptual framework

2.1 Project team and approaches used

It was anticipated that addressing the key challenges of the potato value chain in an integrated approach would stimulate increased potato productivity, incomes and food and nutrition security outcomes of the farm households. The research team constituted staff and organisations with multidisciplinary backgrounds and experiences relevant for this project. The team members were academia and researchers at Universities (Makerere University and Gulu University), Research and Extension organisations (NARO-KAZARDI), Community-Based Organisation (EHC), a potato business incubator and processor (UIRI), and a private sector (Agromax (U) Ltd).

The above Project partners were purposively selected because they were already working with the target group, so they had vast experiences, facilities and networks beneficial to the project. For instance, KAZARDI located in South-western Uganda is the country's producer of potato foundation seed for different agro-ecological zones and has potato demonstration gardens. It collaborates with farmer associations which supply the foundation seed to its members. The members produce certified seed and sell it to other farmers. UIRI has been offering incubation services in potato processing and value addition and local market development. Excel Hort Consult Ltd (EHC) has been promoting potato production, value addition and market linkages in South-western Uganda using a combination of approaches: Famer Field Schools, Agribusiness Incubation and Market Access Networks. Agromax has been multiplying a variety of seeds and seedlings (including potato) for the farming community. Its involvement will strengthen the university-private sector relationship. Similarly, partnering with Bukalasa Agricultural College, a TVET Institution located in Central Uganda, strengthened the university-TVET institutions relationship. The Institution hosted potato production experimental trials and demonstrations, and provided staff and students to participate on the project. The key roles of each of the partners are summarised in Table 1.

Table 1: Project partners and their roles

Partner	Roles of partner
NARO-Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI)	Contribute in designing and demonstrating a community-based system for farmers to participate in the production, delivery and use of quality seed; establishment and monitoring of seed potato multiplication screen house and seed production demonstrations
Uganda Industrial Research Institute (UIRI), Kabale Incubation	Contribute in developing and testing new value added potato products; Provide Incubator facility and laboratory analytical services for potato value addition

Excel Hort Consult Ltd (EHC)	Provide Incubator facility and technology incubation; Contribute in setting up Farmer Field Demonstrations, and in establishing market linkages
Agromax (U) Ltd	Contribute in establishing and monitoring of seed potato multiplication screen house and seed production demonstrations
Bukalasa Agricultural College	Host potato production experimental trials and demonstrations; provide staff and students to participate on the project; provide extension services to the participating farmers and farmer groups.

During the maiden visit to the project area by the Project team, the Diocese of Kigezi under the stewardship of the **Rt. Rev. Bishop George Bagamuhunda** was found very instrumental in driving the agenda of the CARP+ project. The project therefore brought on board the Diocese with a Memorandum of Understanding (MoU) as an Associate Partner. The partner provided over 5 ha of land at Rugarama hill for experiments, farmer field demonstrations and screen house construction; provided agricultural extension staff whose salary was paid by the Diocese, free water for the screen house, and stores and security for the harvested potato. Actually, this Rugarama site was the biggest and busiest project site.


[L] Project team meeting with Bishop of Diocese of Kigezi in his office at Rugarama
[R] Bishop shows project team the land to use

Project team, the Bishop and his clergy touring the land offered to the project

The Project had a Principal Investigator, **Prof. Johnny Mugisha,** who has done various

studies in potato value chain with vast experience in project and research management. In addition to providing overall coordination of the project, he participated in addressing some of the project objectives and supervising students' academic work. The PI had collaborating research scientists who took lead in addressing specific project objectives based on their research and academic competencies. The disciplines/expertise and roles of each team member are summarised in Table 2.

Table 2: Members of the Research Team and their roles

Team member	Institution	Discipline	Roles/Responsibility
Prof. Johnny Mugisha	Makerere University	Agricultural Economics	Overall Project coordination, Contributed to Objectives 1, 2, 3, 4,5; Supervise students
Dr. Peter Wasswa	Makerere University	Plant Virology/ Biotechnology	Contributed to Objectives 1,2,5; Supervised MSc students
Dr. Jimmy Obala	Bukalasa Agricultural College	Plant Breeding and Seed Systems	Contributed to objectives 1, 2,5; Supervised students
Prof. Charles Kwesiga	Uganda Industrial Research Institute	Food Technology Engineer	Contributed to objectives 3,4
Dr. Abel Atukwase	Makerere University	Food Science and Technology	Contributed to objectives 3,5; Supervised students

Dr. Alex Barekye	NARO-KAZARDI	Plant Breeding/ Agronomy	Contributed to Objectives 1,2,5
Mr. Amos Mutayomba	NARO-KAZARDI	Agronomy	Contributed to Objectives 1,2
Mr. Alemeshet Woldemariam	Agromax (U) Ltd	Private Sector	Contributed to Objective 1
Mr. Stephen Kalule Wamala	Gulu University	Socio-economics/ Community-Action Research	Community mobilization and community-action research processes
Dr. Gabriel Karubanga	Makerere University	Agricultural Extension Education	Contribute to farmer groups and farmer training processes; Supervised PhD student
Assoc. Prof. Jeninah Karungi	Makerere University	Agronomy/ Entomology	Supervised MSc students
Dr. Gaston Tumuhimbise	Makerere University	Food Science and Technology	Supervised MSc student

Much as each partner had a leading role, the community-action research approaches used were participatory with active involvement and interactions of the target group (ware and seed potato farmers, processors, consumers and TVET Instructors). The team also had students (PhD, MSc and BSc Interns) registered at Makerere University and Diploma students at Bukalasa Agricultural College.

This Project had five main interlinked components; (1) the seed potato value chain, (2) crop intensification production system, (3) postharvest handling, (4) value addition and (5) market linkages (Figure 1).

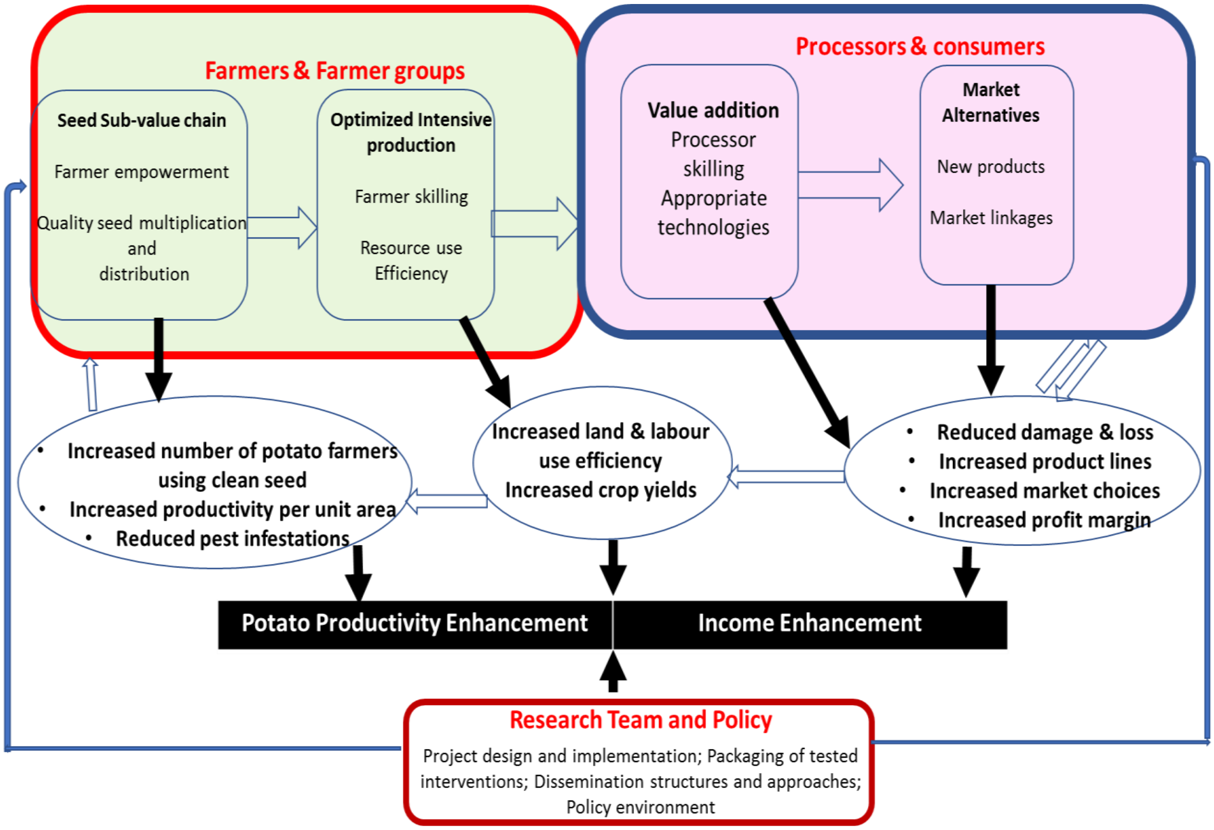


Figure 1:Conceptual framework for making potato value chain enhance productivity and incomes

2.2 Innovativeness of the Project

There has been limited participation of farmers in the seed potato value chain; in production, handling and distribution of quality seed. This is largely due to weak linkages between the plant breeders who provide early generation seed, the private sector seed producers, the seed inspection and certification processes and the farmers who lack empowerment to multiply and sell quality seed potato. This project strengthened the linkages and build the capacity of the farmers to participate in the value chain. In addition, previous research concentrated on potato as a sole crop (in isolation of other crop enterprises). However, in practice farmers grow potato with other crops either as monocrop or intercrop using scarce resources, which the research interventions and recommendations have not put into account, hence limited or no adoption and low impact on productivity. This project overcame this oversight by testing and recommending crop intensification options and giving farmers a platform to participate in the research processes which provided them alternative production practices and technologies to choose from.

Furthermore, processing and consumption of potato in Uganda has also been limited to fresh tubers, and ready-to-eat chips and crisps; some of which are not professionally prepared. This project developed innovative potato-based value added products with great potential for commercialisation. The other innovativeness was the involvement of Mid-Level Cadre students. The project introduced them to research and practical skills that other projects had not done before, yet these are the personnel that work directly with communities. Besides, the students belong to the age bracket (the youths) where unemployment in Uganda is very high. This project enhanced their competence to serve the communities and/or to be self-employed as young entrepreneurs, contributing to the objectives of the Uganda National Youth Policy and other NGOs and initiatives in the country that aim at skilling the youths.

2.3 Methodology

The Project used methodologies that enabled the potato value chain actors especially the farmers to actively participate in the research processes. The Project used multi-stakeholder innovation platforms frameworks, with potato as the entry point. The choice of the Innovation Platforms methodology was based on a variety of literature that acknowledges them as promising pathways for increasing the impact of agricultural research and development. The platforms have been widely used with reported successes (Tenywa *et al*., 2010; Eneku *et al*., 2013; Amede and Sanginga, 2014; Dror *et al*., 2016). The Platforms brought together the potato value chain actors, value chain supporters and policy makers (local government) to facilitate collective visioning, stakeholder analysis, sharing of skills and knowledge, developing and implementing action plans, and promoting the uptake/use of project findings. Within the Innovation Platform framework (Figure 2), the project designed and implemented; 1) Farmer Field Demonstrations (modified Farmer Field Schools), 2) Laboratory based work, and 3) Technology incubation and marketing.

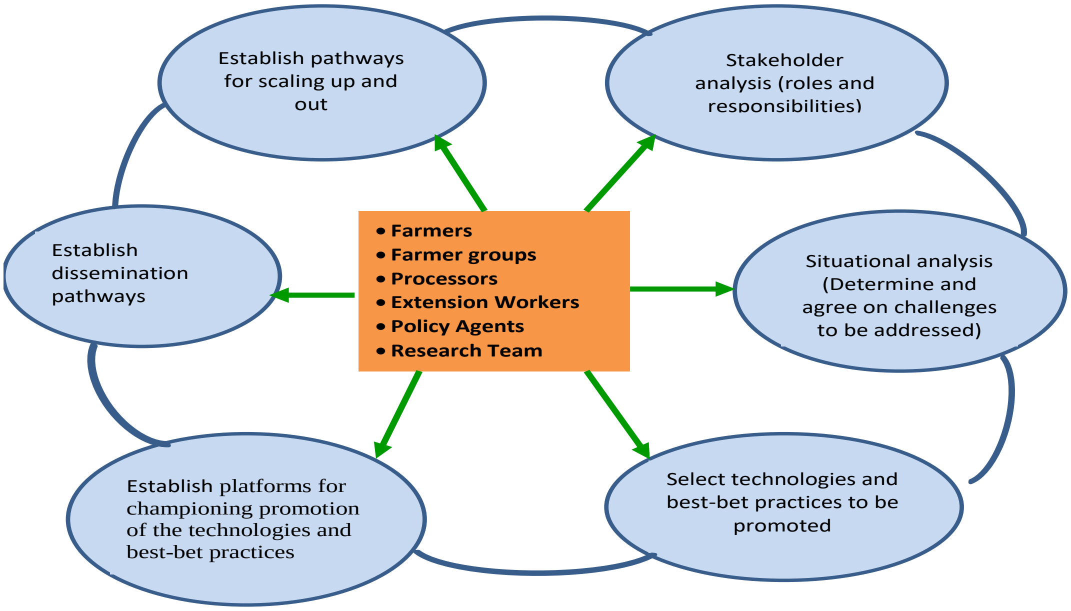


Figure 2: Potato-based Innovation Platform framework for project implementation

The Farmer Field Demonstrations were set up in selected locations in the project areas. It is in these demonstrations that trainings tailored to the value chain actors were offered in seed production and distribution; good practices in optimised crop intensification, and good postharvest handling practices (technologies for harvesting, handling, curing, and improved storage structures). In addition, laboratory work was done in developing and testing new value added potato products. The MSc and PhD students were involved in all the activities from which they generated data for their Theses, journal publications, and conference papers and posters. Undergraduate students were also involved supporting the graduate students mainly in data collection.

2.3.1 Test and demonstrate a community-based system for farmers to participate in the production, delivery and use of good quality seed potato

Potato-based Innovation Platforms (PIPs) were used to carry out a stakeholder analysis and situational analysis as regards the seed potato value chain and the end users of the potato and potato products. The PIPs identified cost effective technologies and practices that produce quality seed; building on the knowledge and practices by the farmers who had been preserving their own seed and potato growers' associations that had been producing foundation seed. The promising practices were piloted in a private public partnership mode with communities/ farmers in centrally selected sites. The project established another seed multiplication screen house at a strategic location (easily accessed by the target group) in the project area. Data were collected on investment requirements and benefits, and farmers' capacity to invest in the seed system. One MSc student assisted by a BSc Intern Student did further analysis to establish the physical and economic viability of investing in the community-based seed system.

2.3.2 Test and validate a system of potato intensification (SPI) that optimises farmers' resources

In the first phase of the Project, experimentation was done on selected on-farm station(s) for at two consecutive seasons to establish the best bet sustainable crop intensification (SCI) technologies and practices. Two approaches were used. The first dealt with developing and testing a system of potato intensification (SPI) for sole crops guided by principles of SCI as defined by Adhikari *et al*. (2018), which include using (i) high quality seed potato, (ii) optimally wide plant spacing to minimise competition, (iii) well-aerated top soil around the potato plant by use of raised seedbeds, (iv) avoiding water-logging by using raised beds that are correctly orientated, (v) application of organic matter, and (vi) reduced application of inorganic fertilizers and pesticides. In other words, the crop intensification basket involved quality seed + appropriate variety + appropriate cropping system + good fit pest and soil management approaches. In the second approach, various intercropping combinations of potato and other crops, such as potato-maize, potato-beans, and in different component mixtures (such as 1:1, 1:2, 2:1) were designed and tested. The intercropping came in under cropping system with the perspective of pest management, amelioration of unsuitable climatic conditions, soil modification and reduction of risk of crop loss. On identifying suitable best-bet SPI and intercropping, agreement with the farmers and farmer groups was made to select sites that were easy to access by the target group, and Farmer Field Demonstrations were then set up where the best-bet crop intensification technologies and practices were demonstrated.

The layout of the demonstrations was scientifically done (using appropriate experimental designs) to allow for statistical analysis and comparisons. The demonstrations were farmer-managed with the research team playing a guiding role. The demonstrations were run for two consecutive seasons. Participatory training sessions (managed by experienced Facilitators) were conducted at every critical stage of the crop production cycle. A similar methodology had been used in Kapachorwa, Uganda in a project titled "Crops for Healthy Diets: Linking Agriculture and Nutrition" also coordinated by the Principal Investigator of this proposed project. Field observations and comparisons were made by the stakeholders. Qualitative and quantitative data were collected, including farmers' perceptions and attitudes; input requirements; outputs and yield differences; risks, marginal cost and marginal benefit differences. The factors attributed to these differences were established and discussed. Further analysis was done by an MSc student and partly a PhD student to determine the yield, income, food and nutrition benefits of potato-based crop intensification systems, and establish a system(s) that optimises these benefits given farmers' resource envelope, their current farming system, and other exogenous and risk factors. The Graduate students were assisted by two BSc Interns. The findings were presented to and discussed by the Innovation Platforms to agree on which intensification options to promote and the dissemination pathways to use.

2.3.3 Develop and test innovative potato-based value added products with potential for commercialisation

The Project developed and tested a variety of potato-based value added products including pre-processed frozen chips, potato flour, and ready to eat snacks (cookies, cakes, waffles, daddies, chapati). Two MSc students were involved in product development. Product development was done at the Department of Food Technology and Nutrition Makerere and Uganda Industrial Research Institute. The testing for consumer acceptability was undertaken by MSc students and TVET Institution (Bukalasa) students in urban areas (Kabale, Kisoro, Mbarara, Wobulenzi, Luwero, Kampala). Products with good consumer acceptability were further developed into protypes for commercialisation. The potential entrepreneurs were trained at Makerere University, Uganda Industrial Research Institute and Excel Hort Consult.

2.3.4 Determine market potential and profitability of the potato-based value added products and promote market linkages for the products

The Project conducted a situational market analysis of produced potato products in terms of their supply and demand, and the actors involved including their knowledge and perceptions on production and use/consumption of the products. One MSc student assisted by Bukalasa Diploma students and one Makerere BSc Intern student conducted market studies and estimated potential market demand of the products. They determined the socio-economic and institutional factors that could influence the supply of and demand for the products. The market studies determined consumer willingness to buy the value added products. Economic viability of commercialising the products was also determined.

3. Community-participation model for farmers in the production, delivery and use of quality seed potato

Uganda's current potato yields of about 4.3t ha^{-1} lags below the potential output of 25 t/ha (Namugga *et al*., 2017). This low yield is attributed to a number of constraints such as limited land for production, poor crop management, climatic changes, reducing soil fertility, use of poor quality seed, pests and diseases, high cost of inputs, poor market prices among others (Tadele, 2017). Use of poor quality seed and poor crop management practices are reported to be the key factors leading to low yields.

Basing on the huge gap between the actual and potential potato yield in Uganda, there was need to understand farmers' knowledge of existing sources of seed potato farmers plant and current management practice challenges at household level. Such information is important for designing a suitable intervention. The Project used Focus Group Discussions (FGDs) to deeply understand farmers' personal attributes, their level of knowledge and skills to ensure high level of adoption.

3.1 Potato-farmer Platform

Building on the FGD findings, the Project organized 15 farmer groups, taking into account gender balance and age difference to cater for the youthful farmers. The groups were given clean seed potato from Kachwekano-ZARDI, NPK fertilizer and other agro-chemicals to control pests and diseases. This was to make farmers to appreciate the significance of using clean seed compared to the conventional recycled seed. Some groups wanted to intercrop potato with other crops like cabbage, carrots, onions, maize and beans; others wanted organic manure to compare with NPK. The project provided them with the required seed and manure. Land was freely provided by individual farmers in addition to what was offered by the Church of Uganda (Diocese of Kigezi) at Rugarama hill in Kabale district, Bukalasa Agricultural College at the College in Wobulenzi, Luwero and Excel Hort Consult at Biharwe in Mbarara district. In Rubanda, land was offered by one farmer, Mr. Kenneth Jogo Biryabarema, in Kagarama village. In Rukiga district, Dr. Frank Mwesigye offered land in Noozi village.

Farmers ranking production constraints associated with potato growing in their communities

Focus group discussion with farmers in Rubanda district

Of the 15 farmer groups, four groups (named A, B, C and D) were at Rugarama site, Kabale district, and five groups in Rubanda district at Kagarama site, two groups at Mbarara district, Biharwe site and four groups at Rukiga district, Noozi site. Moderated by the project research team, each group discussed, and amongst themselves come up with a potato crop intensification practice and implement it on their respective gardens.

3.2 Mitigating seed quality problem through a community participatory research

Since potato is vegetatively propagated, the quality of seed is a significant determinant of crop performance and final yield. In Uganda, majority of potato farmers almost solely obtain seed from unregulated informal sources, for example, their own farms, local markets, stores and fellow farmers. This seed is often of poor quality characterized by continuous re-use for many seasons leading to accumulation of seed borne diseases.

Moreover, farmers habitually use very tiny tubers which are more susceptible to diseases. Farmers are unaware of the importance of seed quality, consequences of recycling and use of tiny tubers eventually leading to appalling potato productivity.

In Uganda, Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI) spearhead the country's quality seed potato production and supply. However, the institute has limited capacity to meet the ever growing demand for seed potato. Private sector players and specialized farmers backstop KAZARDI's limited capacity but good quality seed still remains a scarce and expensive commodity for the poor farmers who alternatively use informal seed.

Research has brought forth significant technologies to improve the quality of seed potato such as seed plot technique and positive seed selection. However, these technologies have not been resourceful. In Uganda, research is often produced independently of farmers consequently leading to low adoption and improper implementation of initiatives. Furthermore, practices such as seed dressing/treatment that has been demonstrated to have enormous importance in regards to potato seed quality is hardly used in Uganda because farmers are ignorant about it. In summary, farmers need knowledge about the importance of seed quality and through participatory research they also need to be skilled on how to produce good quality potato seed, management and maintaining seed quality.

3.2.1 Project interventions

The Project capitalized on the knowledge and skills gap and supported a total of 103 farmers from four different districts of South-western Uganda. Here, a community participatory approach was used where community-researcher managed experiments were set up. In addition, a total of 25 students from a TVET institute (Bukalasa Agricultural College) were skilled in similar practices.

Selection of districts: South-western Uganda was selected because it is the hub of potato production. Four districts namely; Kabale, Rubanda, Rukiga and Mbarara were selected. The gravity of seed quality problem, prominence and potential for potato growing in the region were some of the criteria used for selecting the above districts.

Maiden visit, stakeholder and associate partner meetings: On 28th -31st May 2018, the Project team travelled to south western Uganda with the aims to; gain a more practical understanding of the potato seed value chain where KAZARDI and a prominent seed producer was visited; share the project ideas, its objectives and intended activities with the associate partners and other key stakeholders and agree on specific sites suitable for the project activities.


[L] Meeting with some of the project partners in Kabale district, [R] one of the visited prominent seed producers in Kabale demonstrating the seed production procedure

Site selection: In Kabale district, the project site was at Rugarama. In Rubanda it was in Kagarama, while in Rukiga and Mbarara districts was in Noozi and Biharwe, respectively. The criteria for site selection included; suitability of land for experiments, and strategically located and easily accessed by the communities. Thereafter, soil testing was done.


Experiement site selection visits; [L] Rugarama site [R] Biharwe site

Focus group discussions (FGDs): As one of the Project approaches where it builds on the current farmers' knowledge and practices, FGDs were held at different selected sites. Farmers were selected by identified local leaders. There was no criterion for farmer selection as long as the person was a potato farmer and willing to participate. However, gender equality was emphasized. FGDs were aimed at gaining an in-depth understanding of farmers' knowledge, practices, challenges and recommendations along the seed value chain.


Conducting of Focus Group Discussions (FGDs): [L] Rukiga district; [R] Rubanda district

Land preparation: Farmers who participated in the FGDs and any other farmers who were willing to participate did land preparation. This involved bush clearing, primary and secondary cultivation using hoes and suitably preparing the fields for potato cultivation.

The experiments/trials: Community-researcher managed experiments were set up at different sites where willing farmers participated at every stage of the experiment. Information for setting up the trials was obtained from the FGDs. The objectives of the experiments were to evaluate the effect of seed sources, seed size and seed dressing on potato performance and yields.

- The most widely adopted potato variety; Rwangume was used for the experiments.
- Seed potato was procured from two major sources identified by farmers; farmer own saved and local market. In addition, quality seed from KAZARDI was included as a check.

- The seed was sorted, as usually done by farmers, into two seed sizes i.e. large (35-55mm) and small (less than 35mm). Seed sorting also removed the rotten, highly diseased and damaged tubers.
- Treatment of seed of different sizes and sources was done by dipping soil-free tubers in a systemic fungicide (50g/20L) for 1 to 2 minutes. Thereafter, the tubers were evenly spread on a flat surface and shade dried before planting the following day. However, some seed was not treated to act as a check
- Shallow furrows were dug in a line and fertilizer (NPK) was applied in them. Thereafter NPK was properly mixed with the soil. A sisal string held at both ends was used to obtain straight furrows
- For planting, a spacing of 75cm by 30m was used. Sticks of the above dimensions were employed to obtain the desired spacing. The potato was placed in the furrows and properly ridged (average ridge size was height: 18cm, width: 50cm)
- The plots were properly labelled for easy identification by farmers. Other agronomic practices were done. These included; weeding twice, earthing up and three spraying regimes against pests and diseases (1 prophylactic and 2 curative sprays)
- During the growing season, 3-week periodic visits were done at the sites and data taken. However, farmers were also encouraged to often pass by and note any changes they could see in the different plots before the periodic visits
- 14 days after dehaulming, the experiments were harvested by farmers using hoes. The yield from the different plots was graded in different sizes (large, medium and small) and weighed.

[A] Seed treatment [B] setting up the field [C] digging of furrows [D] fertilizer application [E] Planting of experiment [F] Harvesting of experiment

Participation of TVET students and staff: A group of TVET students from Bukalasa Agricultural College located in Wobulenzi, Luwero district (central Uganda) also participated in the project activities. The first cohort had 25 students. A similar experiment as above was set up at the College and managed by the students following the same procedures as for the farmer-managed experiment.

TVET Students in experimental activities: [A] digging furrows [B] spraying [C] harvesting and data taking

3.2.2 Quality seed production, management and use

Lack of access to quality seed potato is a major bottleneck in potato value chain not only in South-western Uganda but the entire country. For example, in 2015 the demand for seed potato in Uganda was estimated at 239,328 tons but KaZARDI only produced 29,200 kg to seed multipliers putting seed availability at only 0.12%. Majority of the farmers recycle own seed or get it from informal sources where quality is not guaranteed. This leads to seed degeneration and build-up of tuber-borne diseases and hence low yields. As a way of mitigating this problem, strategies such as tissue culture to rapidly multiply the seed tubers have been tried by KaZARDI. However, these are expensive for most developing countries and thus unsustainable.

The Project demonstrated multiplication of quality seed under the screen house system. Led by Agromax Ltd, one of the project partners, a screen house was constructed at Rugarama site in Kabale district on a piece of land offered by the Diocese of Kigezi.

[L] Farmers planting potato a screen house ***[R] Germinated potato in a screen house***

Taking advantage of the controlled conditions, basic seed supplied by KAZARDI was multiplied in the screen house. The harvest was replanted in the open fields at Rugarama site. This site is close to the diocesan church and therefore is easily accessed by a large population of farmers. The harvested potato (seed) from the open fields was distributed to members of the project farmer groups. Individual members planted the seed on individual gardens but under the monitoring and supervision of the group. The seed was given to the farmers at no cost. However, the model was such that on harvest, each farmer would return twice the amount of seed he/she received. The returned seed was then distributed to other farmers who had not received in the first round. This screen house-farmer model helped farmers to access quality seed and also to practice the good agronomic practices the project demonstrated to them.

Facilitated by the project scientists, MSc and PhD students, extension workers in the respective districts, and NARO scientists, the he project trained the farmers (in their respective groups) in various aspects of the potato value chain. Emphasis was on seed selection, seed management, agronomic practices, and postharvest handling.





Overall observations by farmers and students

- On assessing the collected seed, seed from KAZARDI had pure Rwangume with most tubers having almost similar sizes which they regarded as recommended. Both seed from the local market and own saved seed were reported to possess mixed varieties, a lot of variations in sizes, diseased, rotten and damaged tubers. Own saved seed was ranked the worst with these attributes
- During emergency, farmer own saved seed germinated slowly and fewer numbers of seedlings were observed and others completely never germinated.

Little differences were observed between the emergency of seed from KAZARDI and local market.

- Generally treated seed emerged more slowly than the non-treated seed
- No difference was observed in the emergency of the different seed sizes
- During the growing season, generally seed from KAZARDI was reported to grow more vigorously and at the same rate. They also added largely it was a pure stand with 1 or 2 plants of other varieties. Seed from the local market was rated as good-fairly vigorous though it had more mixtures than KAZARDI's seed. Own saved was rated as fair-poor vigorous and some plants were also reported as stunted. own saved seed was said to have the most mixed varieties and the leaf canopy was not so thick.
- Non-treated seed was said to be more vigorous with a thicker canopy than treated seed
- Big seed size was also reported to be more vigorous with a thicker canopy than small size seed.
- They reported that all the plots were badly affected by mostly late blight and bacterial wilt.
- Some farmers in some sites reported that mainly cut worms were destroying the crop. Other pests reported were caterpillars.
- They also observed that after curative spraying, the crops that had late blight recovered and new leaves were produced while most of those that had bacterial wilt dried off and died
- Generally, farmers also noticed that own saved seed had the fewest number of crops to reach physiological maturity. Some of them had died off. This was followed by seed from the local market and the highest numbers of crops to reach physiological maturity were from seed from KAZARDI
- Generally, small size seed had the least number of crops to reach physiological maturity compared to large size seed
- The yield obtained from KAZARDI was reported as the highest with more of marketable size tubers (big), some seed size tubers (medium), very few very tiny tubers and diseased. Local market yield was ranked the second with some marketable size tubers, more seed size tubers and relatively tiny tubers and diseased. Own saved seed had more of the tiny tubers, some seed size tubers and very few marketable seed and a high numbers of diseased tubers

- Small seed size tubers were generally reported as having produced more very tiny tubers, a few seed size tubers and the fewest marketable tubers. Large seed performed better with more marketable size, seed size and a few tiny tubers
- Non treated seed was reported to perform better in terms of yield compared to treated seed
- Few cut/injured potatoes during harvesting were observed compared to what the farmers said they obtain.

Lessons learned by farmers and students

- Early and well preparation of fields is important for potato cultivation.
- Early planting in the season is key for good potato productivity.
- Fertilizer is important for good potato yields and it is vital to put the fertilizer close to where the plant can easily obtain it instead of broadcasting it.
- Proper spacing and proper ridging is key in bulking of potato
- Monitoring of the crop is important because it helps one identify issues easily and deal with them immediately.
- Diseases are both in the seed and in the soil. So it is important to select good seed and if possible good soil for potato cultivation.
- Spraying is very important for disease and insect control and it can help to rescue the crop which would otherwise have died. This also helps in maintenance of seed quality
- Some diseases like bacterial wilt cannot be cured by spraying but can be prevented by planting disease-free seed.
- It is very important to sort seed very well before planting to remove the diseased, rotten, cut, mixtures and choose the right size. This also has to be done before storage
- KAZARDI has good quality seed followed by local market and lastly their own saved seed thus they needed to do much to improve the quality of their own saved seed.
- It is important to obtain seed from a good source if good yields are to be realised. Good seed equates to good yields i.e. good seed quality is important for good yields
- Seed size is key to potato productivity. The seed size they habitually use gave them lower and poor quality yields compared to the recommended seed size.

- Proper ridging and careful harvesting reduces losses due to mechanical injury caused by harvesting tools.
- Students learnt how to do agronomic data taking and also got exposure to farming practices and cultures of South western Uganda

Challenges that farmers reported in implementation of the lessons

- Unreliable weather patterns characterised by erratic rainfall patterns and prolonged droughts leading to improper planning of the field activities thus crop loss or very poor yields.
- The inputs for example fertilizer and pesticides are expensive and inaccessible. Farmers have limited/no money to purchase them whenever needed and often they use non recommended amounts leading to low productivity and loss of the crop.
- Fake agro-inputs on the market and farmers cannot differentiate them.
- Good quality seed from KAZARDI which they desire to use is highly priced, inaccessible and most times the variety they need is produced in limited quantities.
- Seed from the market is also relatively expensive and sometimes they cannot afford to buy it thus they use their seed
- Using good quality seed is not profitable since it is bought expensively but little money is obtained on selling the harvest i.e. low prices and little or no market for their produce
- Limited knowledge on the attributes of good quality seed so most times inferior seed is sold to them or they end up planting poor quality seed.
- Limited land to practice the recommended spacing.
- Lack of time to do field monitoring, early planning of activities and sorting of seed because they are engaged in a number of jobs inorder to obtain enough money for home essentials
- Big size and medium tubers are usually sold for money or eaten and end up leaving tiny tubers for seed

3.2.3 Effect of seed source and seed size on performance of potato

The Project repeated the seed experiment alongside farmer-managed demonstration gardens for two more consecutive crop seasons beginning with the second season of 2018 (2018B) and during the first season of 2019 (2019A). One MSc student of Crop Science at Makerere University, **Monica Kigambo**, working with farmer groups and other cohorts of TVET students, took the lead. This formed part of her MSc. Thesis titled ***"Effect of seed sources, seed tuber size and seed dressing on the performance of potato and late blight incidence in Uganda"***

Kigambo's experiments for her Thesis were in three districts representing two agro-ecological zones (AEZ); Kabale and Rukiga in south-western highlands AEZ and Mbarara in south-western grass farmlands AEZ. The study sites are characterized by two major potato growing seasonsin a year. The first season also referred to as season A generally runs from February to June during the first rains. The second season also referred to as season B generally runs from September to January during the second rains.

Before land tillage was done, soil samples were collected from each of the experimental sites across the three districts. Soil sampling was done following the method described by Taylor and Francis (2006). This method was chosen because it reduces the sampling and testing costs owing to reduced number of samples while maintaining acceptable information about nutrient variability within a field. The samples were analyzed for the different properties in the soil laboratory at Makerere University following parameter proceduresdescribed by Okalebo *et al*. (2002).

Seed of Rwangume variety was collected from Kabale district which is the most prominent potato growing district in Uganda (Mukhwana and Ogemah, 2005; Namugga *et al*., 2017). This variety was chosen because it is widely adopted by farmers, highly marketable and high yielding (Namugga *et al*., 2017). Seed was obtained from two commonly used seed sources namely; farmer-saved and local markets from where farmers usually obtained seed. Certified seed from KaZARDI was also included to serve as a control for the assessments. Seed from each source was bulked together thus in total three seed lots (Farmer- saved, local market and certified-KaZARDI) were obtained. The obtained seed lots were properly sprouted, fumigated against storage pests and kept under ambient conditions until planting time. Before planting, the tubers from each seed lot/source were sorted to remove the rotten, highly diseased and damaged. They were graded into small size (<35 mm) and the recommended large seed size (35-55 mm) tubers (Burke, 2011) to enable for testingthe effect of size on potato growth and yield for each seed source. From each seed source and each size grade, half of the tubers were treated with a fungicide suspension while the other half was left untreated to allow for testing the effect of seed treatment on potato growth and yield for each seed source. A method modified from Haveri *et al*. (2018) was used to do seed treatment. For each seed source and seed size grade, soil-free tubers were obtained and dipped in victory 72 WP (metalaxyl 80g/kg and mancozeb 640g/kg) suspension for 1 to 2 minutes.

The experiment consisted of three factors (seed source, seed size and seed treatment). The experimental layout was a randomized complete block design in a split-split-plot arrangement, which were replicated thrice. Seed source was the main-plot factor with three levels (farmer-saved, local market and certified KaZARDI); seed size was the split-plot factor with two levels (small: < 35 mm and recommended large: 35-55 mm), while seed treatment was the split-split-plot factor with two levels (untreated and treated with Victory 72 WP fungicide); thus, it was a 3 × 2 × 2 factorial experiment giving a total of 12 treatments (plots) per replicate. Each plot was 3.5 m × 3.65 m consisting of five rows which accommodated 12 plants per row. The recommended potato spacing i.e. 0.75 m between rows and × 0.3 m within rows was used (Burke, 2011). In total, there was a plant population of 60 plants per plot. The spacing between plots and adjacent replications was 1 m and 2 m, respectively.

Primary tillage was done followed by secondary tillage using hand hoes at all the experimental sites to give fine seed beds for potato growing. Shallow furrows of about 4-5cm were then dug ina straight line. Using band application, nitrogen (N), phosphorus (P) and potassium (K) fertilizer (NPK 17:17:17) (Export Trading Group Inputs Limited, Nairobi, Kenya) was applied in the furrows at planting using a rate of 1.096t/ha as recommended by KaZARDI agronomists. After covering the fertilizer with some soil, potato tubers were placed in the furrows at the recommended potato spacing of 0.3m between tubers and 0.75m between rows. There after ridging was done using hand hoe. Ridges of average height (17cm) and width (59cm) were used.Two weedings were later performed by hand hoeing at 4 and 9 weeks after planting. Earthing-up was also done concurrently. Spraying against insect pests and fungal diseases was done twice during the growing season at 4 and 9 weeks after planting for both prophylactic and curative purposes. Spraying was done after data collection. The fungicide Mistress 72 WP (cymoxanil 8%and mancozeb 64%) (Osho chemical industries limited, Nairobi, Kenya) was applied at the recommended rate of 30g/20L. The insecticide *Dudu Ethoate* 40 EC (Elgon Kenya limited, Nairobi, Kenya) was used at a recommended rate of 40ml/20L. Plants infected by bacterial wilt were rouged out whenever identified. Two weeks before harvesting, the stems of the potato plants were cut off using a knife to the level of the soil (dehaulmed) in order to promote hardening of the potato skin and reduce disease spread from the foliage to the tubers. Harvesting was done by hand hoeing on dry days to avoidcarrying wet soil on tubers to the store.

Data were collected on sprout length, number of sprouts, size of tubers, tuber skin appearance: presence of disease or damages, number of sprouts per eye, and genetic quality. Other data variables collected on plant basis include plant height, number of main stems and leaf length. On plot basis, data were collected on plant emergence, late blight incidence, graded yield and total yield.

The average length of sprouts, number of sprouts and size of tubers was determined. Percentage genetic quality (purity or contamination) was also determined by converting the obtained numbers from each category into percentages of the total assessed tubers. Plant and plot basis data were subjected to analysis of variance (ANOVA) using Genstat 14th edition software to assess for homogeneity/heterogeneity of variance among the study environments (locations and seasons).

Generally, certified seed obtained from KaZARDI (control) had healthy, short, thick and strong sprouts growing in an upright position with average length of 6.6 mm. The sprouts had a purple base with a white tip. 18 out of 20 (90%) of the assessed tubers had one sprout growing from each eye while only 2 tubers (10%) had more than one sprout growing from each eye. The skin of all the assessed tubers had no wrinkles. Only 2 out of the 20 assessed tubers (10%) showed slight visible disease signs while the rest of the 18 tubers (90%) had no visible disease signs. For genetic quality, most assessed tubers were of Rwangume variety giving a genetic purity of 90% with 10% contamination by tubers of Victoria variety. The size of the large tubers was averagely 47.8 mm in diameter having an average of 4 sprouts growing from each tuber. The average size of small tubers was 27.4 mm in diameter having an average of 3 sprouts growing from each tuber (Figure 3).

Figure 3: Certified seed from KaZARDI (a) large size (b) small size

For farmer-saved seed source, 17 out of 20 (85%) of the assessed tubers had weak, long white sprouts growing in a bent position although 2 tubers (10%) had very short sprouts while 1 tuber (5%) had no sprouts. The average sprout length of the assessed tubers was 18.2 mm. 18 out of 20(90%) of the assessed tubers had more than one sprout growing from each eye which was either branched or hairy. Only 1 of the tubers (5%) had one sprout growing from the apical end of the tuber and 1 tuber (5%) had no sprout growing from the tuber eyes. The skin of 16 out of 20(80%) of the assessed tubers was rated as slightly wrinkled while the skin of 4 of the tubers (20%) was rated as very wrinkled. Furthermore, while 14 out of 20 (70%) of the assessed tubers showed no visible disease sign on tuber surface, 4 of the tubers (20%) were slightly infested and damaged while 2 of the tubers (10%) were very infested and damaged. For genetic quality, this seed lot had an array of varieties and these included: Victoria, Kinigi, Kimuli and Mbumba giving a percentage genetic contamination of 40% while the rest of the tubers were of pure Rwangume seed giving a genetic purity of 60%. The size of the large tubers was averagely 42.2 mm in diameter with averagely 5 sprouts growing from each tuber. The size of small tubers was on average 20.7 mm in diameter with an average of 4 sprouts growing from each tuber (Figure 4).

Figure 4: Farmer-saved seed (a) large size (b) small size

For local market seed source, 15 out of 20 (75%) had weak, long white sprouts growing in a bentposition. However, 2 tubers (10%) had very short purple sprouts while 3 tubers (15%) had no sprouts. The average sprout length of the assessed tubers was 14.2 mm growing in a bent position. Although 2 out of 20 of the tubers (10%) had one sprout growing from each eye, 15 of the assessed tubers (75%) had more than one sprout growing from each eye which were mostly branched while 3 of the assessed tubers (15%) had no sprouts growing from the tuber eyes. The skin of 13 out of 20 (65%) of the assessed tubers had no wrinkles while 7 tubers (35%) were rated as slightly wrinkled. In addition, although 15 out of 20 assessed tubers (75%) showed no visible disease symptom on the tuber surface, 5 tubers (25%) were slightly infested and damaged. Genetic purity was 70% (pure Rwangume variety), with a genetic contamination of 30% with seed tubers of Victoria and Kinigi variety. The size of the large tubers was on average 41.3 mm having averagely 4 sprouts growing from each tuber. The size of small tubers was averagely 18.1 mm in diameter having averagely 3 sprouts growing from each tuber (Figure 5).

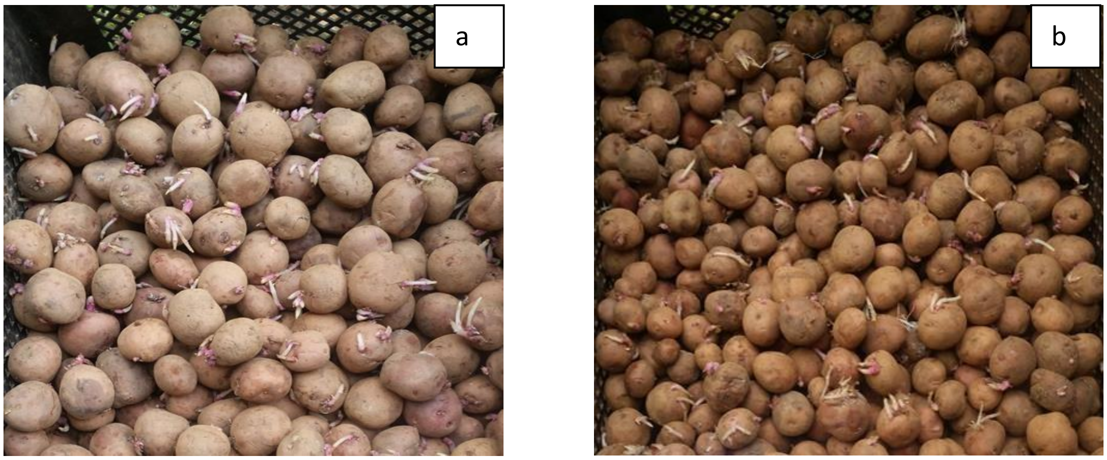


Figure 5: Local market seed (a) large size (b) small size

Certified seed from KaZARDI resulted in significantly the highest yield of medium-size and total tubers. The lowest yield of medium-size and total tubers was recorded in seed from the local market source which was significantly similar to that obtained from farmer- saved seed. Moreover, the highest yield of large-size tubers was obtained from certified seed, followed by farmer-saved seed while seed from the local market source provided the lowest yield of large-size tubers. Yield of small-size tubers significantly ranged from 2.93 t/ha in local market seed to 2.22 t/ha in certified seed (Table 3).

Table 3: Effect of seed source on potato yield parameters across south-western Uganda for seasons 2018B and 2019A.

	Number of tubers (%)			Tuber yield (t/ha)			
Seed source	Small	Medium	large	Small	Medium	Large	Total tubers
Certified seed	57.99±21.37[a]	24.27±11.36[b]	17.31±11.85[b]	2.22±1.03[a]	2.78±1.86[b]	3.59±2.63[c]	8.60±4.68[b]
Farmer-saved	68.39±14.93[b]	21.20±9.66[a]	11.19±7.39[a]	2.41±1.14[b]	2.23±1.36[a]	2.37±1.83[b]	7.00±3.86[a]
Local market	74.20±12.74[c]	19.14±10.39[a]	7.95±5.88[a]	2.93±1.57[c]	2.20±1.41[a]	1.82±1.52[a]	6.95±4.06[a]
L.S.D (0.05)	2.75	2.32	3.27	0.26	0.16	0.40	0.34

Values are means ± SD. Values in a column with the same superscript are not significantly different ($P > 0.05$).

Significantdifferences (P < 0.05) in the number of large-size tubers as well as yield of tubers in terms of sizeof small, medium and total tubers were observed between large-size seed and small-size seed (Table 4). However, there was no significant effect (P > 0.05) of potato seed size on the number of small and medium-size tubers as well as yield of large-size tubers. Plots planted with small-size seed resulted in significantly a higher number of large-size tubers compared to plots of large-size seed. The results further showed that plots planted with large-size seed significantly resulted in a higher yield of small, medium and total tubers compared to plots of small-size seed.

Table 4: Effect of seed size on potato yield parameters across south-western Uganda for seasons 2018B and 2019A.

	Number of tubers (%)			Tuber yield (t/ha)			
Seed size	Small	Medium	large	Small	Medium	Large	Total tubers
Large	67.19±17.85^{a}	22.06±11.61^{a}	11.27±8.72^{a}	2.76±1.38^{b}	2.63±1.79^{b}	2.49±1.99^{a}	7.89±4.49^{b}
Small	66.53±18.19^{a}	21.02±9.64^{a}	13.02±11.19^{b}	2.28±1.36^{a}	2.16±1.33^{a}	2.69±2.25^{a}	7.14±4.17^{a}
L.S.D (0.05)	1.71	3.36	1.67	0.16	0.25	0.30	0.36

Values are means ± SD. Values in a column with the same superscript are not significantly different (P > 0.05).

Seed source x seed size interaction was significant (P < 0.05) for number of large-size tubers as well as yield of medium, large and total tubers (Figure 6). Use of small-size certified seed from KaZARDI significantly resulted in the highest number of large-size tubers although it was statistically similar to large-size certified seed from KaZARDI. The next best treatment seed source and seed size interaction for number of large-size tubers was small-size farmer-saved seed. The lowest number of large-size tubers was observed in small-size local market seed although it was par with large-size local market seed (Figure 6a).

For yield of medium-size tubers, use of large-size certified seed form KaZARDI significantly resulted in the highest value. The lowest yield of medium-size tubers was recorded in small-size local market seed although it was statistically similar with large-size local market and farmer- saved seed as well as small-size certified seed from KaZARDI and small-size farmer-saved seed (Figure 6b).

For yield of large-size tubers, plots with small-size certified seed from KaZARDI significantly resulted in the highest values. This was followed by plots with large-size certified seed from KaZARDI. The lowest yield of large-size tubers was noted in small-size local market seed although it was par with large-size local market seed. Both small and large-size farmer-saved seed resulted in statistically similar yield of large-size tubers (Figure 6c).

Large-size certified seed from KaZARDI resulted in significantly the highest total tuber yield. This was followed by small-size certified seed from KaZARDI. The lowest total tuber yield was noted in small-size local market seed. Large-size local market and farmer-saved seed as well as small-size farmer-saved seed resulted in statistically similar total tuber yield (Figure 6d).

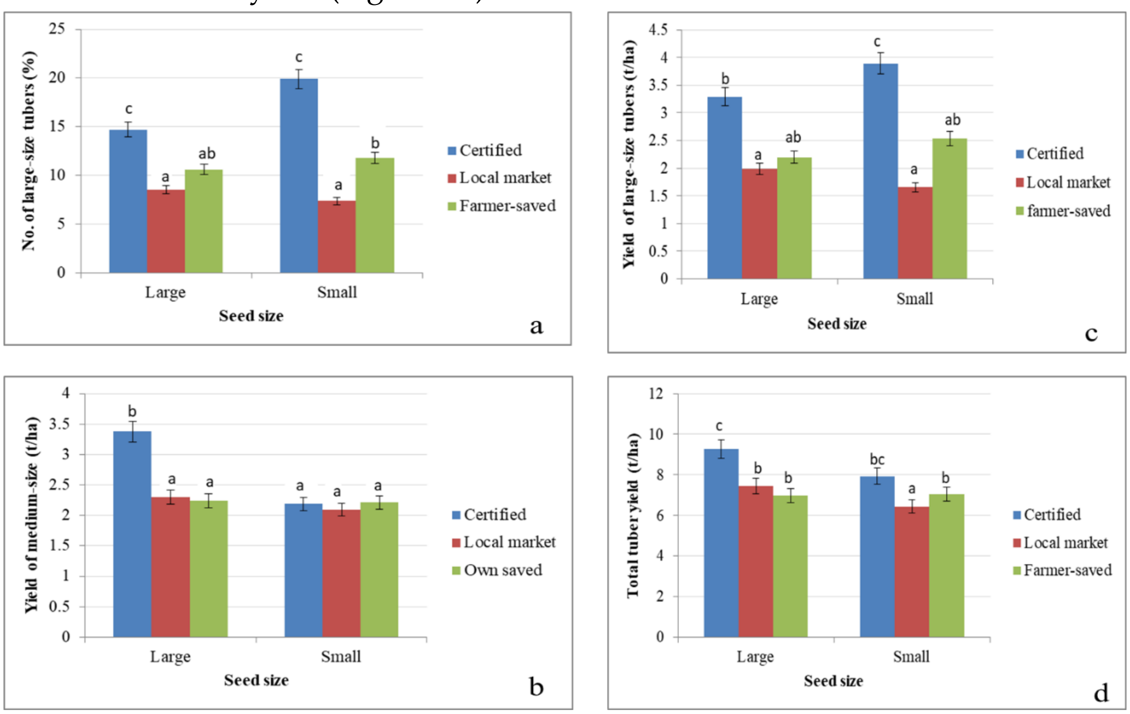


Figure 6: Effect of the interaction of seed source and seed size on (a) number of large-size tubers (b) yield of medium-size tubers (c) yield of large-size tubers and (d) total tuber yield

It was, therefore, concluded that (i) seed source influences the quality of potato seed and has a significant effect on a number of potato growth and yield parameters; (ii) seed size has a significant effect on a number of potato growth and yield parameters with large-size seed (35-55 mm) exhibiting outstanding field performance; and (iii) fungicide seed treatment significantly improves the number of medium-size tubers, yield of medium-size and total tubers compared to untreated seed.

The study recommended that farmers should be trained to accurately identify potato seed with good quality characteristics; and always source the seed of quality. Certified seed is primarily recommended for potato production. Efforts to make certifiedseed more available and accessible to farmers should be put in place. In the event that certified seed is inadequate and cannot satisfy the demand, farmer-savedseed could be used provided the seed is of large-size and fungicide-treated. Efforts shouldbe put in training farmers in production and management practices that improve and maintain the quality of on-farm produced potato seed. The first choice among potato tuber seed sizes should be accorded to large-size seed (35-55 mm), regardless of seed source. Small-size tubers (< 35 mm) should be explored for alternative uses as this will give farmers certainty regarding the fate of the obtained smalltubers consequently encouraging use of large size tubers for seed. Fungicide seed treatment should be incorporated in potato production. Farmer trainings, sensitization and promotional campaigns about potato seed treatment should be organized.

3.2.4 Solving seed scarcity through use of seed cuttings

Given the limited availability of potato seed, the Project found it prudent to identify and test other feasible and cost-effective methods of propagating potato to achieve optimum benefits both in terms of yield and net returns. Use of potato tuber cuttings is very rare in Africa. The main advantage about this method is that quite a less amount of seed potato is required during planting. Nolte *et al*. (2003) in their experiment concluded that cutting tubers and treating them with a fungicide dust is better protection against dry rot and stem canker than whole tubers. The study further noted that cutting and treating tubers can improve yields suggesting that treated seed-pieces work best.

The project experimented propagating potato using tuber cuttings as a potential method of reducing the farmers' demand gap for quality seed potato. This project activity was led by one MSc. Student of Crop Science at Makerere Univeristy, **Masiko Muhafuzi**, working with members of farmer groups in Kabale district and the extension officer of the Diocese of Kigezi. From this activity, he is writing MSc Thesis titled "***Potato cutting propagation for optimum growth and yield in Kabale, Uganda***". The focus was to determine the effect of cut potato seed tuber pieces on potato growth and yield parameters; and the economic viability of propagating Uganda potato varieties using cut tubers.

Tubers of quality seed for the varieties commonly grown in South-western Uganda (Rwangume, Victoria and Kachpot 1were cut either longitudinally or cross-sectional ensuring each cut piece bore at least an eye and was treated with mancozeb 80 WP.

The experiment design was a complete randomized block design with three replications. Treatments consisted of 6 combinations of variety, and propagation method, that is, treatment T1; Rwagume whole seed potato, T2; Victoria whole seed potato, T3; Kachpot whole potato seed, T4; Rwangume cutting+mancozeb 80 WP, T5; Victoria cutting+mancozeb 80 WP, T6; Kachpot 1 cutting+mancozeb 80WP.

At 3 weeks, data was taken on germination rate by counting the number of sprouts in each experimental plot and at 6 weeks on plant height, stem number and compound leaf number will be taken from 9 plants in the three middle rows. Dehaulming was done manually at 81 days and harvesting will be done seven days later. Tuber number and yield were recorded at harvest from the whole produce of the plot. The yield performance data was analyzed by analysis of variance (ANOVA) using GenStat 14th edition. Where the ANOVA indicated significant ($P \leq 0.05$) difference, the means were separated using least significant difference.

Results revealed a significant difference in germination rate across treatments ($P=0.037$). Whole potato seed gave a higher mean germination rate than cut tubers for Rwangume and Victoria varieties. However, this was different for Kachpot 1 variety (Table 5).

Table 5: Effect of seed tuber cutting on germination rate and plant height of Uganda potato varieties

Propagation method	Mean germination rate (%)	Mean plant height (cm)
Rwangume whole seed tubers	95.3	77.07
Rwangume cut seed tubers	77.3	64.56
Victoria whole seed tubers	93.0	52.30
Victoria cut seed tubers	88.7	52.59
Kachpot 1 whole seed tubers	73.0	67.44
Kachpot 1 cut seed tubers	79.3	58.63

A significant difference was noted in plant height across the treatments ($P<0.001$). Plant height was generally higher where whole seed was used compared to cut potato tubers. However, the trend is reversed for the Victoria potato variety. Rwangume whole seed achieved the highest plant height (77.07cm) followed by Kachpot 1 whole seed (67.44cm) and Victoria whole seed had the lowest (52.3cm). The difference in plant height between whole potato seed and cut potato seed is more pronounced for the Rwangume (12.63cm) and Kachpot 1 variety (8.81cm), with a negligible difference for the Victoria potato variety (0.29cm). There was a significant difference in the number of stems for the different treatments ($P= 0.025$) with Rwangume whole seed and Victoria whole seed having the highest mean number of stems (3.148) while Kachpot 1 seed cutting had the least (2.444). Generally, Rwangume potato variety had the highest number of stems while Kachpot 1 potato variety had the least (Table 6).

Table 6: Effect of seed tuber cutting on number of stems and leaves of Uganda potato varieties

Propagation method	Number of stems/plant	Number of leaves/plant
Rwangume whole seed tubers	3.148	60.6
Rwangume cut seed tubers	2.963	73.8
Victoria whole seed tubers	3.148	44.7
Victoria cut seed tubers	2.556	59.4
Kachpot 1 whole seed tubers	2.667	64.4
Kachpot 1 cut seed tubers	2.444	78.1

Save Rwangume variety, cutting performed better than whole seed tubers on the parameter of tuber number (Table 7). However, was no significant difference in the number of potato tubers for the different treatments (P=0.171). Victoria produced the highest number of tubers (514.2) while Kachpot 1 whole seed produced the least number (245.7).

Table 7: Effect of potato seed cutting on yield components

Propagation method	Number of tubers/15sq.m	Yield (ton/ha)	Net yield (ton/ha)
Rwangume whole seed tubers	293.7	11.80	8.67
Rwangume cut seed tubers	307.7	11.68	10.11
Victoria whole seed tubers	269.0	11.08	9.41
Victoria cut seed tubers	514.2	17.39	16.57
Kachpot 1 whole seed tubers	245.7	9.06	6.48
Kachpot 1 cut seed tubers	337.3	9.61	8.34

Similarly, no significant difference in yield was recorded across the different treatments (P=0.402) with Victoria cutting giving the highest yield (17.3ton/ha). For all the three varieties cutting averagely performed better than whole seed tubers.

It is therefore economically efficient for potato farmers in South-western Uganda to propagate potato using cuttings. Treating the cuttings before planting improves the performance of the cut seed. This technology should be promoted among the small-scale farmers who have limited resources and access to quality seed potato.

4. Farmer participatory evaluation of potato intensification practices for enhanced productivity

In Uganda, potato production is mainly concentrated in the highlands of south western Uganda. These prominent potato growing areas are characterised by rapid population growth consequently resulting in land fragmentation and shrinkage of arable land. This has compelled majority of the potato farmers to practice mono-cropping which insufficiently fulfils their nutritional and economic needs. This practice has also tremendously contributed to soil exhaustion and disease accumulation in these areas. Nevertheless, some farmers grow potatoes alongside a wide range of crops, but not appropriately done.

In the above circumstance, it becomes crucial to improve land use efficiency in order to enhance potato production in Uganda. The use of the system of crop intensification (SCI) has been documented to improve land use efficiency and as a result it noticeably enhances crop performance in a wide range of crops. This system embraces the adoption of a set of practices like optimal plant spacing, minimal use of inorganic fertilizers, use of quality seed and intercropping with locally available companion crop. However, most potato research in Uganda focuses on improving potato as a sole entity in isolation of other crops. Additionally, no attempts have been made to evaluate the system of crop intensification (SCI) in potato cropping systems in Uganda. This implies research has not fully benefited potato farmers leading to low adoption of research recommendation and thus continuous use of unsuitable practices which result in poor yields.

The potato CARP+ Project established farmer-researcher managed experiments in three districts of South-western Uganda. In addition, farmers mobilised into groups put up some trials alongside the experiment plots to compare the efficiency of their agronomic practices with the recommended practices. In Luwero district, similar experiments were set up jointly managed by the project researchers and TVET students of Bukalasa Agricultural College. In total 146 farmers (65 men, 64 women and 17 youth) and 25 TVET students participated. The project envisioned the involvement of these students as one way of expanding the project impact by skilling them with demonstrated technologies so that they can disseminate them to the communities they would serve after graduation.

In order to identify and fully understand the research gap, the project organised a familiarization visit to the intended research districts in south western Uganda. The districts included; Kabale, Rukiga and Mbarara where areas in those districts i.e. Kagarama, Noozi and Biharwe, respectively, were selected and visited. Random field tours were done to look at the existing potato farming systems and practices. In addition, focus group discussions (FGDs) were conducted in the three selected areas where information regarding farmers' agronomic practices, challenges, interventions done to mitigate challenges and suggestions of possible way forward were obtained. A maximum of 14 farmers per site participated. In total 34 farmers (15 women and 19 men) participated. Meetings with key stakeholders and partners were also conducted. The key findings were;

- Both mono-cropping and intercropping were observed in the areas. However, the former was the most prominent cropping system and farmers also reported to mainly practice it. Potato was mainly intercropped with maize and beans but with no definite plant arrangement. Ratios of 1:1, 2:1, 3:1, 5:1 potato: companion crop were reported. Other companion crops included sweet potato and sorghum.

- Ridging and flat seed bed were observed in the visited fields but the latter was commonest practice and earthing up was not sufficiently done. However, most farmer when asked reported to practice ridging and sufficiently earth up.

- Line and random planting were observed in the visited fields but the latter was the commonest with no definite spacing. Those who practiced line planting used non recommended spacing. Farmers reported to do line planting using spacing of 1ft by 1ft and 1.5ft by 1.5ft which they estimated using their feet.

- Use of fertilizers, quality seed and pesticides was not common.

[L] Focus group discussion in Mbarara district [R] project members visiting one of the farmer's field in Rukiga district

Using the information obtained from the FGDs, farmer-researcher managed experiments were set up at the three selected sites. All willing farmers participated in all stages of the experiment, from land clearing to harvesting. The experiments were intended to develop an optimised and sustainable cropping system under a range of agro-ecological conditions, biophysical production capacity and socio-economic factors. In the end the project intended to come up with up with "farmer-developed and owned" alternative interventions for the value chain actors to choose from.

Rwangume variety and NABE16 bean variety were used. Four practices were chosen, i.e., (i) potato spacing at 3 levels (75x30cm-recommended spacing, 60x50cm-square planting, 40x30cm-farmers' usual spacing); (ii) cropping ratios at 5 levels (1 row of potato: 1 row of beans; 1 row of Potato: 2 rows of beans; 2 rows of potato: 2 rows of beans; 1 row of potato: 0 row of beans; 0 row of potato: 1 row of beans); (iii) ridging at 2 levels (ridging and flatbed); and (iv) fertilizer (NPK) application at 2 levels (NPK application and no NPK application).

Potato were planted in line furrows that were made using the help of a sisal string held at both ends. Sticks of the above dimensions were used to obtain the desired measurements. Beans were sown in between the potato rows. For plots that required fertilizer, split applications was done where half of the required amount per plot was applied at planting and the remaining half at second weeding. Fertilizer was applied in potato furrows and mixed with soil. Other agronomic practices such as weeding, disease and pest control were done. Three-week periodic visits were done by both farmers and researchers to observe any changes and take data on agronomic performance.

[A] Digging of furrows
[B] Planting potatoes
[C] Planting beans
[D] Harvesting beans
[E] Harvesting potatoes

The Project provided the farmers with seed, fertilizer and pesticides in order to set up trials of their desired interests using their agronomic practices that they felt they needed try out but could not do them on their farms because of limitations such as small land, lack of inputs etc. The farmers at site organised themselves in groups depending on common interest in particular agronomic practices. The groups were;

Kabale, Rugarama site	1. **Group A**: consisted of 9 women and 2 men. Practices were; sole potato, line planting, use of inorganic fertilizer and ridging 2. **Group B**: consisted 20 girls from Drucilla Barbara School. Practices were; potato-cabbage intercrop planted at 1 row of potato:1row of cabbage, ridging 3. **Group C**: consisted of 13 women and 2 men. Practices were; potato-bean intercrop, flat beds, randomly planted, bush beans and inorganic fertilizer. 4. **Group D**: consisted of 7 women and 1 man. Practices were; potato-bean intercrop, line planting plant using a spacing of 30cm by 30cm, 1row of potato:1 row of beans, ridging, bush beans
Mbarara, Biharwe site	1. **Group A**: consisted of 5 men and 2 women. Practices were; potato-tomato intercrop. 1 potato row: 1 tomato row, spacing of 1ft from potato row to tomato row, inorganic fertilizer used 2. **Group B**: consisted of 2 men and 1 woman. Practices were potato-maize intercrop, 1potato row: 1 maize row, inorganic fertilizer
Rukiga, Noozi site	1. **Group A**: consisted of 13 women. Practices were; potato-bean intercrop, line planting, flat bed, bush beans, organic fertilizer, 1 row potato: 1 row beans 2. **Group B**: consisted of 3 men and 6 women. Practices were; potato-maize intercrop, organic fertilizer, spacing of 1 row of potato: 1 row of maize 3. **Group C**: consisted of 3 men and 3 women. Practices used were; sole potato, no fertilizer, line planting, a spacing of 2ft from one potato row to another

[L] Farmers choosing among themselves what groups they wanted to belong; [R] One of the farmer groups in Kabale setting up their experiment

The different farmer trials were compared among the groups and also compared with the farmer-researcher experiment. This enabled to come up with the best “farmer-developed and owned” interventions for improved potato productivity.

Similar experiments like the farmer-researcher managed experiments were set up in Luwero district at Bukalasa Agricultural College where the TVET students, MSc students and researchers jointly managed the experiments and data collection.

[L] and [M] TVET Students digging furrows, [R] students spraying

From the above experiments, the farmers made the following key observations:

- ridged plots agronomically performed better than flat beds. The yield from ridged plots was said to be higher comprising majorly of large tubers. Yield from flat beds was reported to comprise largely of small tubers
- the recommended spacing (0.75x0.3m) and square planting (0.6x0.5m) equally performed the same in both field and yield performance. Farmers' usual spacing (0.4x0.3m) was reported to perform the worst in both field and yield performance with the yield comprising of majorly small tubers.
- In terms of cropping ratios, the ratio of 1 potato row: 1 beans row was reported to perform the best in terms of yield. 2 rows of potato: 2rows of beans was reported to perform the poorest terms of yield. Potato mono-cropping (1 row of potato: 0 row of beans) was also said to give good yields.it was however noted that the sole treatments for both potato and beans were associated with a high disease incidence and severity for the respective crops than it was with intercrop treatments.
- All plots where fertilizers were applied were reported to perform better than plots with no fertilizers in terms of yield.
- Potato-bean and potato-maize intercrops by some farmer groups were reported to perform better. Other intercrops like potato- onion, potato-carrot, potato –cabbage, etc. were reported not to be set up properly and timely thus they performed the poorest
- Farmers reported that there was no difference in agronomic performance between use of organic manure and inorganic fertilizer.
- Line planting was reported to ease field activities like weeding, fertilizer top dress, ridge construction, spraying and proper intercropping. It was too named to give better quality and quantity of potato than random planting

The farmers therefore chose the following interventions for promotion and adoption:

- Cropping ratio of 1 row of potato: 1 row of beans, spacing 0.6x0.5m, and ridging and use fertilizer was the intervention chosen by majority of farmers.
- A combination of 0.6x0.5m spacing, ratio of 1 row of potato: 0 row of beans (potato sole cropping), ridging and use fertilizer was chosen by some farmers.
- Potato-maize and Potato-bean intercrop were also chosen using a ratio of 1:1, ridging, line planting and use of fertilizers.

Agronomic practice tested	Observations made by farmers	Farmer choices
1. Seed bed		
• i. Ridging	Many marketable size tubers	Ridging
• ii. Flat bed	Fewer marketable size tubers and many small tubers	
2. **Spacing**		
• i. 0.75x0.3m	A good number of marketable and seed size tubers	0.6x0.5m
• ii. 0.6x0.5m	A good number of marketable and seed size tubers	
• iii.0.4x0.3m	Few marketable and many small sized tubers	
3. Cropping ratios		
• 1P:1B	Many marketable size tubers Better bean yield	1P:1B
• 1P:2B	Fewer potato marketable tuber sizes More bean yield than in 1P:1B	
• 2P:2B	Many small sized potato Less bean harvest compared to 1P:2B	
• sole potato	Many marketable size tubers Few seed size tubers Few small sized tubers	
4. Fertilizer		
• Fertilizer application	Many marketable size tubers and very few seed and Small sized tubers.	Fertilizer application
• No fertilizer application	Many seed size tubers Equally the same quantity of small sized tubers	

Under this project component, a PhD student of Agricultural and Rural Innivations at Makerere University, **Rolland Ainebyona**, is writing a PhD Dissertation titled, "***Potato (Solanum tuberosum) crop intensification innovation: A case of smallholder farmers in South-western Uganda***". He examines the processes involved in attitudes and experiences of smallholder farmers towards potato crop intensification, and determines the impacts of potato crop intensification on smallholder farmers' welfare. He also assesses the socio-economic and institutional drivers of smallholder farmers' engagement in potato crop intensification initiatives.

The CARP+ Project repeated the crop intensification experiment alongside farmer-managed demonstration gardens for two more consecutive crop seasons; 2018(2018B) and 2019 (2019A). Working with the farmer groups, an MSc student of Crop Science at Makerere University, **Justine Nakubuule** led this activity guided by the project scientists TVET students and BSc Interns. From this activity, she developed her MSc. Thesis titled "***Response of potato (Solanum tuberosum* L.*) to manipulation of row spacing, fertilizer use, and intercropping with beans***".

Nakubuule used Rwangume variety obtained from KaZARDI. She also got one bean bush variety (NABE16) from the National Crops Resources Research Institute (NaCRRI), Legumes Research Programme for her experiments. This variety was preferred because of its suitability in all agro-ecologies, its high marketability, and its preference by farmers. The choice for beans as the potato-intercrop was because of the many associated benefits like contributing to nitrogen stocks, biological nitrogen fixation, improvement of soil physical and chemical properties (Meena and Lal, 2018), and the nutrition benefit to farmers as a source of proteins.

A split- split plot randomized complete block experiment was established at each of the three on-farm-based sites for two consecutive seasons. The study had three factors: plant row arrangements of a potato-bean intercrop, potato spacing, and fertilizer treatment. Plant row arrangements were in the main plots, potato spacing in sub-plots, and fertilizer in sub-sub plots.The treatments that were tested are;

(a) Plant row arrangement levels: one row of potato to one row of beans (1P:1B),one row of potato to two rows of beans (1P:2B), two rows of potato to two rows of beans (2P:2B); sole potato, and sole bean.
(b) Two levels of potato spacing: 75 cm × 30 cm recommended potato spacing by NARO-KaZARDI, and 60 cm × 50 cm square planting adopted from the System of Crop Intensification (SCI).
(c) Two fertilizer levels: plots treated with NPK (17: 17:17); and plots with Zero NPK treatment (untreated control).

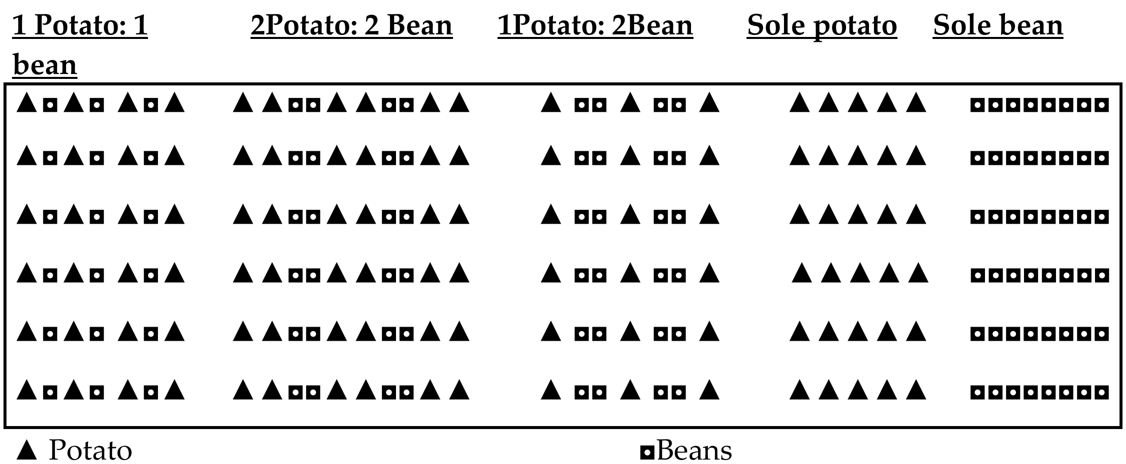


Figure 7: Schematic representation of different row arrangements of potato and beans in sole and intercropping systems

The first weeding and hilling up of potato ridges was done three weeks after planting whereasthe second was done two weeks after the former to suppress emerging weeds. At 21 days afterplanting (DAP), less vigorous bean seedlings were rogued out during weeding to maintain a population of one plant per hill. The intercropping proportions of potato and beans with their respective total number of plants per treatment are presented in Table 2.

Fertilizer application using NPK 17:17:17 was carried out in two split doses; one at planting and the other at 3 weeks after planning (WAP). At planting, fertilizer was placed below the seed before soil cover whereas the second dose was administered at weeding as top dress following guidelines by Mehdi *et al*., (2016). Sole bean plots were given130g split quantity at planting following recommendations by Mehdi *et al*., (2016) using the rate of 20 kg/ha recommended for beans by the National Beans Program at the National CropsResources Research Institute (NaCRRI) – Namulonge.

Prophylactic spraying of fungicides and curative spraying was routinely done at 2-weeks intervals against fungal diseases, especially late blight (caused by *Phytophthora infestans*) forpotato. Mistress® 72 composed of Cymoxanil 8% w/w +Mancozeb 64% w/w was used at a rate of 30 g per 20 L alternated with victory ® 72 WP (Metalaxyl +Mancozeb) at a rate of 250g per 100L. Insect pests for both crops were controlled at 2-weeks intervals by spraying with Dudu-x Ethoate 40® (Dimenthoate) at a rate of 40 ml per 20 L. At physiological maturity, potato dehaulming was done using kitchen knives two weeks beforetuber harvest to allow skin hardening. Tubers were then removed manually by hoeing. For beans, plants were allowed to completely dry in the field and later harvested by hand pulling. Harvesting all experimental sites was completed by February 2019 and August 2019 for seasons 2018B and 2019A, respectively.

Data were collected on potato shoot height, leaf area (cm^2), number of marketable tubers per plot, number of unmarketable tubers per plot, and total tuber weight per plot (t/ha). These were used as indicator parameters for the crop performance under different treatments. Eight randomly selected plants from the inner harvestable rows per plot were tagged with white threads to allow easy recognition and were used to obtain records of shoot height and leaf length from which leaf area calculations were based.

Dried beans in the field were harvested on sunny days by uprooting bean plants from the innerharvestable rows of each plot to avoid the edge effect. These were threshed by hand, winnowedand the weight per plot was measured using a sensitive balance. Plot yield was first recorded as grams per plot (g/plot) and later transformed to (t/ha) following guidelines by Ejigu *et al*. (2017).

The data were subjected to normality tests by the production of residual plots in Genstat. This wasvery important to ascertain whether the data was in line with the analysis of variance (ANOVA) assumptions. The residual plots produced presented a normal distribution about the mean withhomogeneous variances indicating that the data was consistent with the ANOVA assumption.The data was therefore subjected to ANOVA for the split-split plot design and the separation of significant means was by the least significant difference (LSD) at P ≤0.05 using GenStat Statistical Package 14th Edition. The experimental factors including plant arrangements, potatospacing, fertilizer application, and location were considered fixed factors, and the crop's performance and yield parameters were considered response variables. The land equivalent ratio (LER) was used to report land use efficiency as a measure of intercropping advantage for crop mixtures as compared to their respective sole counterparts. Results indicated that the interaction between location, spacing, and plant arrangement significantly ($p = 0.001$) influenced potato shoot height and leaf area. Location-induced variations among treatments were also highly significant ($p < 0.001$). Potato shoot height was greatly influenced by the combined effect of location and plant arrangements at different levels of spacing. Locational variations among treatments were highly significant ($p < 0.001$).

Results (Table 8) indicated a significant influence of plant arrangement, spacing, fertilizer and location on yield of potato, beans and combined yield. Solely, plant arrangements significantly influenced only bean yield in 2018B and bean, potato and combined yield in 2019A. The highest bean grain yield of 0.70 t/ha in 2019A was obtained from plant arrangement 1P:2B followed by 1P:1B (0.6t/ha) and least from 2P:2B (0.4t/ha) and sole bean. Detailed results can be found in Nakibuule's Thesis.

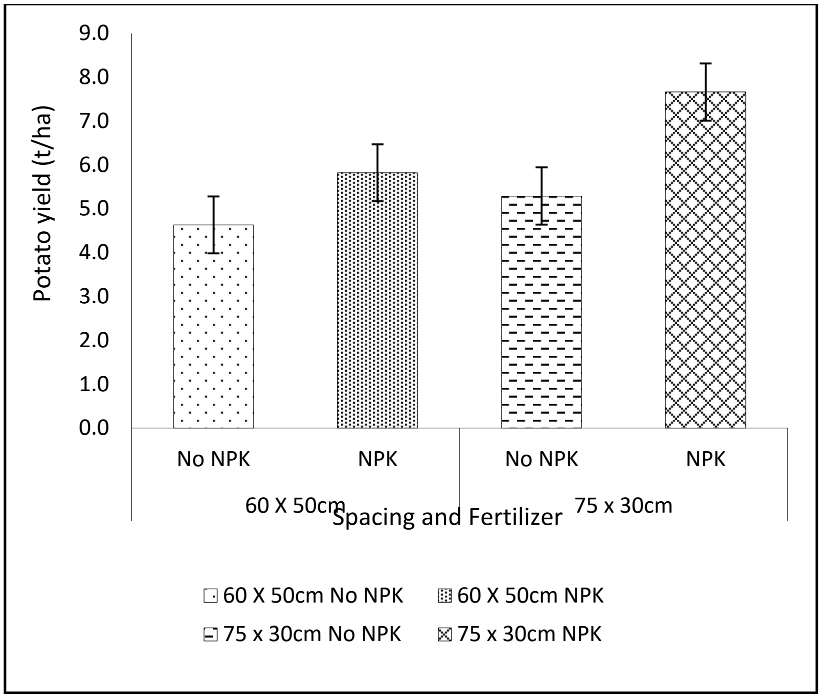
Table 8: Effect of location, plant arrangement, spacing and fertilizer on the potato yield, grain yield and combined potato -grain yield

		Season 2018B			Season 2019A		
Source of variation	d.f.	Bean Yield	Potato Yield	Combined Yield	Bean Yield	Potato Yield	Combined Yield
plant arrangement	4	44.48***	5.98	5.95	24.78**	818.64***	1067.17***
Spacing	1	7.55*	9.38*	10.5*	8.96*	19.39**	20.62**
Plant arrangement. Spacing	4	1.13	2.1	2.1	0.97*	2.38	2.42
Fertilizer	1	7.47*	67.22***	70.25***	0.01	1.27	1.22
Plant_ arrangement. Fertilizer	4	2.88	5.36*	5.06*	3.97*	0.39	0.3
Spacing. Fertilizer	1	0	7.46*	7.32*	3.72	1.35	1.69
Plant arrangement. Spacing. Fertilizer	4	0.75	3.86*	3.79*	0.6	0.82	0.75
Location	2	5.51**	42.94***	43.18***	16.83***	226.83***	216.13***
Plant arrangement. Location	8	1.82	3.59**	3.63**	7.55***	14.79***	13.76***
Spacing. Location	2	0.12	1.43	1.37	1.69	2.94	2.58
Fertilizer. Location	2	0.49	1.95	1.9	5.32**	2.06	1.85
Plant arrangement. Spacing. Location	8	0.3	0.8	0.8	0.32	1.32	1.28
Plant arrangement. Fertilizer. Location	8	0.14	0.42	0.4	0.88	0.23	0.21
Spacing. Fertilizer. Location	2	0.23	0.25	0.26	0.32	1.06	1.17
Plant arrangement. Spacing. Fertilizer. Location	8	0.1	0.48	0.47	0.91	0.6	0.57

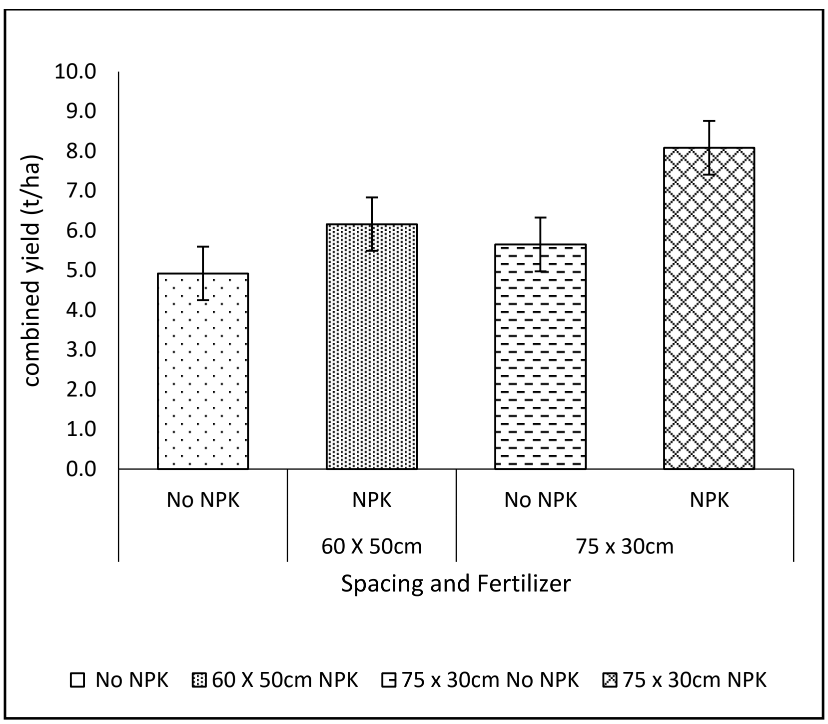
****Significant at 0.001; **Significant at 0.01; *Significant at 0.05; Values without asterisk are not significant statistically; 2019a First rainy season (February-June), 2018 b second rainy season (mid-August- mid-December)*

Potato yield and combined potato- bean yield were superior in intercrops of 1P:2B with higher bean density unlike other plant arrangements with lower bean density. This implies that inclusion of beans in potato cropping systems greatly enhanced both potato yield and total productivity.

Results also revealed an interaction between spacing and fertilizer on potato yield and combined yield. At both spacings, potato yield and combined yield consistently increased with fertilizer use, but the best response to NPK application was in the 75 x 30cm (Figure 8a). Highest potato yield of 7.7t/ha and combined yield of 8.1t/ha were obtained from NPK treated plots of 75x 30cm spacing while the least potato yield of 4.6t/ha and combined yield of 4.9t/ha were obtained from 60x50cm spacing plots without NPK (Figure 8b).



(a)



(b)

Figure 8: (a) Potato yield (t/ha) and (b) Combined potato-bean yield (t/ha) as influenced by the interaction between spacing and fertilizer

The study concluded that

- Changing the spacing to the recommended 75 cm × 30 cm to 60 cm × 50 cm increases shoot height, leaf area, and total potato tuber yield.
- Intercropping potato with beans increases potato productivity in plant arrangement 1P:2B; it results in an extra yield of 1.2 t/ha compared to the sole crop, while the arrangements of 1P:1B and 2P:2B is not significantly different from the sole crop.
- Spacing of 75 cm × 30 cm responds best to the addition of NPK resulting in increasein potato yield and combined yield.
- For the sole arrangement, the spacing of 75 cm × 30 cm produces the highest number of marketable tubers even without NPK whereas, for intercrops, 60x50cm spacing produces the highest percentage of marketable tubers with NPK treatment.
- Total LERs for all the intercropping arrangements is greater than one (> 1) implying that potato-bean intercropping is a viable option for crop intensification, especially forsmallholder farmers.

The study, therefore, draws the following recommendations to the potato farmers in South-western Uganda:

- Intercrop potato and beans because it produces higher potato yield and total combined yield than potato monocrops.
- Commercial potato production should be concentrated in Rukiga and Kabale due to the superior yield and tuber quality exhibited.
- Commercial potato production under mono-cropping systems in Kabale should be done at 60 cm × 50 cm spacing whereas, in Rukiga, it should be done at 75cm × 30 cm
- Application of NPK to 1P:1B intercrops at 60 cm × 50 cm spacing is greatly encouraged for commercial potato production under potato intercropping systems.
- Application of NPK to intercrops of 1P:2B maintained at 75 cm × 30 cm spacing is highly recommended for ware potato production

5. Innovative potato-based value added products with potential for commercialisation

Because of its high productivity (high yield in short time at low cost and throughout the year), potato is an important commodity possessing about 16% carbohydrates, 2% proteins, 1% minerals, 0.6% dietary fibre and some health promoting compounds such as phenolic acids, ascorbic acid and carotenoids. However, the potential of the potato industry in Uganda has not been fully exploited. This has been attributed to limited value addition, low production and productivity and limited investment by both public and private sector in potato value addition. In addition, one of the hidden problem driving potato value addition in Uganda is the lack of sufficient data on the potential of commonly grown potato varieties to support industrial-level processing.

To exploit the market potential of potato through value addition, the potato CARP+ Project screened the nine most common varieties grown in Uganda for their physical, chemical and nutritional characteristics. The relevance of this approach is to determine the potential use of each variety as well as to provide evidence based data needed by researchers and processors in product development and postharvest management, market analysis and investment in any potato-based product, and by farmers interested in commercial farming to make informed choices on the potato varieties to grow. This also enabled to classify potato varieties into two groups namely; potato for table and potato for processing. Three varieties (Kachpot1, Kinigi and Rwangume) with the potential to make frozen French fries were identified and selected, while the non-marketable tiny tubers of all varieties were tested for their potential to produce flour.

5.1 Development of potato-based valued added products

The Project undertook a product research-development process using facilities at the School of Food Technology, Nutrition and Bio-engineering Makerere University and the other partner, Uganda Industrial Research Institute (UIRI), Kabale facility. Screening and characterization of potato varieties were done in different lab well-equipped at Makerere University and the National Crops Resources Research Institute (NaCCRI) in Uganda, as well as at Jomo Kenyatta University of Agriculture and Technology in the Sino-Africa Joint Research Centre in Kenya (SAJOREC).

Screening of the major varieties grown in Uganda generated valuable information on each varieties completing the potato catalogue for multipurpose use. Some of the relevant information are summarized below.

CRUZA

CHARACTERISTICS

Oval round medium tubers with white ringed flesh

Medium Dry matter, High Reducing sugars, Low Starch content

POTENTIAL USES

Salad
Mashed
Flour

KACHPOT1

CHARACTERISTICS

Round medium tubers with light yellow flesh

High Dry matter, Low Reducing sugars, High Starch content

POTENTIAL USES

French fries
Crisps
Flour

KIMULI

CHARACTERISTICS

Round small tubers with cream flesh

Medium Dry matter, Low Reducing sugars, Low Starch content

POTENTIAL USES

Salad
Mashed
Flour

KINIGI

CHARACTERISTICS

Round medium tubers with cream flesh

High Dry matter, Low Reducing sugars, High Starch content

POTENTIAL USES

French fries
Crisps
Flour

MBUMBAMAGARA

CHARACTERISTICS

Round small tubers with white flesh

Medium Dry matter, Low Reducing sugars, High Starch content

POTENTIAL USES

Salad
Mashed
Flour

RUTUKU

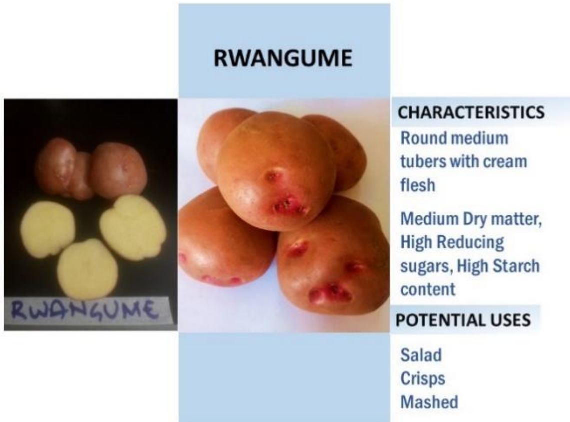
CHARACTERISTICS

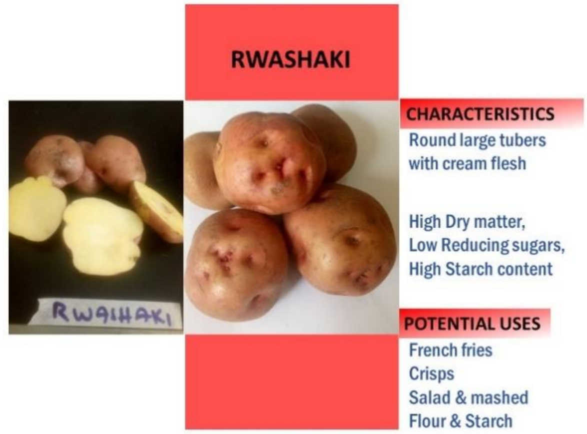
Oval Round medium tubers with cream flesh

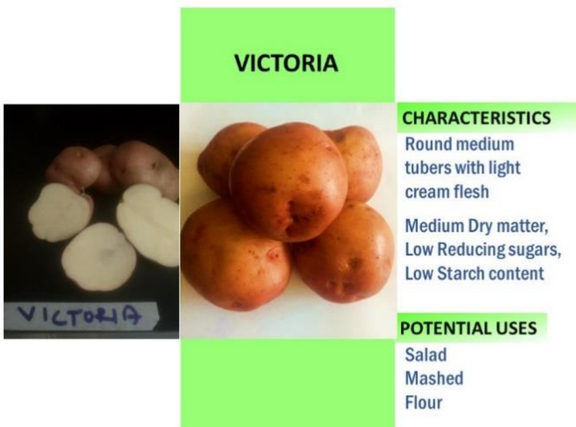
Low Dry matter, Low Reducing sugars, Low Starch content

POTENTIAL USES

Salad
Mashed







Processing French fries involved sorting of potato, peeling, washing, trimming, slicing, blanching, partial frying, cooling, packaging, freezing and storing. The effect of critical unit operations (namely; slicing (size of strips), blanching (time-temperature combination) and storage (time) on quality and the shelf life of French fries were tested.

The study results indicated that potato varieties grown in Uganda have good traits and potential to support the processing industry. Having known the physical and chemical characteristics of the potato are now known, it is now possible to design appropriate postharvest technologies to reduce losses faced by all stakeholders in the potato value chain. There is a need to improve potato varieties with average traits but preferred by farmers for their adaptability to different region. It is also possible to produce frozen French fries from local varieties both to increase farmers and processors income and to satisfy the growing demand for potato processed products.

A detailed study was done by one MSc. Student, **Napoleon Kajunju Bahati**, of Food Science and Technology at Makerere University. He wrote a Thesis titled, *"**Assessing the processing traits of potato varieties commonly grown in Uganda and their potential for producing French fries**"*.

Kajunju washed, cleaned and sliced potato tubers into 10 mm thick transverse slices using a knife. He then freeze-dried them using SCIENTZ-18ND (Zhejiang, China) freeze-dryer equipment. Parameters were set at: freezing temperature: (–56 ± 1°C) for 24h; drying process: (40 ± 1°C) at maximum vacuum (pressure: <10Pa) during 24 h. The dried slices of potatoes were milled into thin powder by using a mortar and pestle and stored in polyethylene bags at room temperature.

Reducing sugars were extracted by the method described by Muttucumaru *et al*. (2013) as follows. One g of the lyophilized powder of each variety was mixed with methanol/chloroform (75:25 v/v) and sonicated. After 15 min the sample was placed in -20oC environment and latter centrifuged at 15000 rpm 5°C. The supernatant was collected and placed in 1.5ml HPLC vial and the solvent dried in vacuum oven. The residue was reconstituted using mobile phase 1.5ml ACN/H2O (75/25).

The sugar content was determined using HPLC equipment (Shimadzu, Japan) with RID-20A refraction index detector (equilibrate at 40oC and well purged using the mobile phase) and a normal phase-amide column Supelco NH2 250mm x 5μm x 4.6mm. Separation temperature for column oven CTO-10AVP was set at 40oC. Automated injections of 20 μl were performed using SIL-20A auto sampler. LC-20AD running on isocratic mode of ACN/H2O (75/25) was set at 1ml/min. The individual sugars (glucose, fructose and sucrose) were identified and quantified by external calibration using Shimadzu Lab Solutions software. Each extract was analysed in triplicate, and the results expressed as g/kg of FW.

The phenolic content was determined according to the Folin-Ciocalteu spectrophotometric method as described by (Singleton et al., 1999). Five (5) g of the homogenized sample were extracted with 50 ml of ethanol water solution (80%) in a conical flask with a magnetic stirrer at 700 rpm for 1 h at room temperature (20±1°C). The potato extracts were then filtered through a filter paper No 89.

About 0.5 ml of the sample extract was added to 2.5 ml of Folin-Ciocalteu reagent (diluted 10 times with water) and, after 3 minutes 2 ml of sodium carbonate (Na2CO3) (75 g/l) were added. The sample was mixed and incubated for 30 minutes at room temperature. The absorbance was determined using a spectrophotometer at 765 nm. The same procedure was repeated for the standard solution of gallic acid and the calibration line was construed. Based on the measured absorbance, the concentration of phenolics was read from the calibration line; the content was expressed in terms of Gallic Acid Equivalent (mg of GAE/100g of potato).

The total flavonoid content was estimated by aluminium chloride method (Quettier-deleu *et al*., 2000). Potato extract samples (0.5 ml) were mixed with 2.5 ml of distilled water and 150µl $NaNO_2$ solution (5%). The contents were vortexed for 10 seconds and left at room temperature for 5 min. Then, 300 µl $AlCl_3$ (10%) were added and contents vortexed and incubated at room temperature for 6 minutes. One (1) ml NaOH (1 M) and 550 µl of distilled water were added. The solution was mixed well and allowed to stand for 15 min. The absorbance for each sample was measured at 510 nm. Total flavonoid content was expressed as quercetin equivalent in mg/100g.

The Tannins (tannic acid) in potato were estimated according to a method described by Saxena *et al*. (2013). 0.2 g of freeze-dried powdered potato was weighed into 250 ml conical flasks and 35 ml water added. The flask was heated gently and allowed to boil for 30 min. The resultant solution was transferred into 50 ml polypropylene tube and topped to 50 ml using deionized water and centrifuged at 1902 x g for 10 min. The supernatant was collected into separate vials. Into a 96 well microtiter plate, 50 µl of sample (supernatant), standards (tannic acid) and blank solution was added followed by addition of 50 µl of Folin–Denis reagent and 100 µl of 7% sodium carbonate solution before mixing by priming using multichannel pipette. The absorbance reading obtained at 700 nm after 30 min. A standard calibration curve of Tannic acid was used to calculate the concentration of total tannins in mg per 100 g of the dry sample.

To determine B vitamins, HPLC-grade solvents were used for analysis. Analytical reagent-grade Methanol was obtained from LOBA Chemicals, India. The water used for HPLC and sampling was prepared with a Millipore Simplicity instrument (Millipore, Molsheim, France). All vitamin standards (Thiamine Hydrochloride, Nicotinic Acid, Pyridoxine Hydrochloride, Folic Acid and Riboflavin) were of chromatography grade and were purchased from Sigma Aldrich, UK.

Quantification of vitamin B content was accomplished by comparison to vitamin B standards. Standard stock solutions of 100mg/l for the following vitamins thiamine, riboflavin, nicotinic Acid, pyridoxine, and Folic Acid was prepared and dissolved in buffer pH 7.0 (potassium di-hydrogen phosphate). The stock solution was adjusted to pH 9.2 to completely dissolve the Folic Acid and Riboflavin vitamins. Chromatographic separation was achieved on a reversed phase- (RP-) HPLC column (SUPELCO C18;

250×4.6 mm i.d., 5 µm) through the gradient elution (Mobile Phase A Methanol 100%) mobile phase B buffer (100 mM potassium di-hydrogen phosphate pH 7.0). Quantification of the vitamins against external standards was performed using Shimadzu Lab solutions 5.97 Software.

Results (Table 9) show significant differences ($p<0.05$) in starch content between *Cruza-Mbumbamagara* (12%), *Kimuli-Victoria (14%), Kachpot1-Mbumbamagara-Rwangume* (19%) and *Kinigi-Rwashaki* (22%). There was a positive relationship between dry matter content and starch content. High dry matter content was associated with high starch content. The results further indicate that reducing sugar content also varied significantly ($p<0.05$) among the major potato varieties grown in Uganda (Table 7). *Rwashaki* (0.54 g/100g FW) and *Kimuli* (0.55 g/100g FW) recorded significantly higher sugar levels than *Kinigi* (0.02 g/100g FW). Significant differences ($p<0.05$) between sucrose, fructose and glucose content of different potato varieties were observed. Glucose was the most abundant sugar in most of the potato varieties. However, sucrose was exceptionally predominant than others sugars in *Kinigi* (0.4623g/100g FW). The fructose content of the potato varieties ranged from 0.0034 g/100g FW in *Rutuku* to 0.0251 g/100g FW in *Kimuli*.

Table 9: Starch and reducing sugars content of 9 potato varieties commonly grown in Uganda

Variety/Variety	Starch (%)	Reducing sugars	Fructose	Glucose	Sucrose
Cruza	12.73 ±1.19[a]	0.49 ±0.03[bcd]	0.0072 ±0.0018[a]	0.49 ±0.03[bcd]	0.34 ±0.21[ab]
Kachpot1 (CIP 382171.4)	19.94 ±0.03[c]	0.47 ±0.01[bcd]	0.0052 ±0.0004[a]	0.47 ±0.01[bcd]	0.27 ±0.08[ab]
Kimuli	14.82 ±0.09[b]	0.55 ±0.16[d]	0.0251 ±0.0035[b]	0.52 ±0.12[d]	0.20 ±0.10[ab]
Kinigi	22.72 ±0.02[d]	0.02 ±0.00[a]	0.0036 ±0.0005[a]	0.01 ±0.00[a]	0.46 ±0.17[b]
Mbumbamagara	20.24 ±0.33[c]	0.52 ±0.04[cd]	0.0058 ±0.0016[a]	0.51 ±0.04[cd]	0.30 ±0.20[ab]
Rutuku (CIP 720097)	12.40 ±0.08[a]	0.41 ±0.00[b]	0.0034 ±0.0007[a]	0.41 ±0.00[b]	0.19 ±0.02[a]
Rwangume (Naropot4)	20.05 ±0.10[c]	0.44 ±0.01[bc]	0.0041 ±0.0006[a]	0.44 ±0.01[bc]	0.18 ±0.09[a]
Rwashaki	23.67 ±0.19[d]	0.54 ±0.01[d]	0.0058 ±0.0009[a]	0.54 ±0.00[d]	0.24 ±0.06[ab]
Victoria (CIP 381381.20)	15.10 ±0.11[b]	0.47 ±0.01[bcd]	0.0046 ±0.0008[a]	0.46 ±0.01[bcd]	0.18 ±0.04[a]

Values are means ± SD. Values in a column with the same superscript are not significantly different (p > 0.05).

Beta carotene in major local potato varieties grown in Uganda ranged from 1.14 mg/100g in *Kinigi* to 1.77 mg/100g in *Kimuli* (Table 10). Significant differences in beta-carotene content were observed between varieties. A higher beta-carotene content was recorded in *Kachpot1* (1.60 mg/100g) and *Kimuli* (1.77 g/100g) than the rest of the varieties. *Rutuku* had the highest content of total phenolic compounds (2329.72 mg GAE/100g) followed by *Victoria* (2146.71 mg GAE/100g) and *Mbumbamagara* (2007.77 mg GAE/100g); while *Rwangume* and *Cruza* recorded the lowest TPC contents (130.00 mg GAE/100g and 73.13 mg GAE/100g, respectively).

Table 10: Beta-carotene, Total phenolic compound, tannins and flavonoids of 9 local potato varieties grown in Uganda

Variety/Variety	Beta-carotene (in mg/100g)	Total Phenolic Compound in mg GAE/100g	Tannins in mg/100g	Flavonoids in mg/100g
Cruza	1.42 ±0.08^{bc}	73.13 ±2.44^{a}	0.13 ±0.01^{b}	3.48 ±0.57^{a}
Kachpot1 (CIP 382171.4)	1.60 ±0.07^{d}	613.46 ±68.48^{c}	0.16 ±0.01^{bc}	19.82 ±0.12^{e}
Kimuli	1.77 ±0.04^{e}	232.38 ±9.85^{b}	0.23 ±0.01^{d}	13.65 ±0.05^{cd}
Kinigi	1.14 ±0.02^{a}	1014.85 ±14.89^{d}	0.34 ±0.02^{e}	4.43 ±0.21^{a}
Mbumbamagara	1.37 ±0.04^{bc}	2007.77 ±43.69^{e}	0.49 ±0.04^{f}	7.23 ±0.43^{b}
Rutuku (CIP 720097)	1.43 ±0.02^{bc}	2329.72 ±50.37^{f}	0.18 ±0.02^{c}	11.62 ±0.56^{c}
Rwangume (Naropot4)	1.36 ±0.11^{b}	130.00 ±1.40^{ab}	0.08 ±0.01^{a}	13.76 ±1.84^{d}
Rwashaki	1.53 ±0.05^{cd}	503.77 ±8.56^{c}	0.24 ±0.01^{d}	27.06 ±0.45^{f}
Victoria (CIP 381381.20)	1.54 ±0.03^{cd}	2146.71 ±115.43^{e}	0.31 ±0.00^{e}	4.98 ±0.70^{a}

Values are means ± SD. Values in a column with the same superscript are not significantly different ($p > 0.05$)

Most of the potato varieties commonly cultivated in Uganda had nearly the same content of B vitamins (Table 11). In the majority of varieties, thiamin content varied from 52 to 71μg/100g while folic acid concentration varied from 118 to 151 μg/100g. However, *Mbumbamagara* had the highest thiamin content (172.78 μg/100g). A significant difference was found between *Kimuli* (7.22 μg/100g) and the other varieties (6.56-6.73 μg/100g) in terms of vitamin B2.

Table 11: Content of B Vitamins (µg/100g) in commonly grown potato varieties in Uganda

Variety/Variety	Thiamin (vitamin B1)	Riboflavin (B2)	Niacin (B3)	Pyridoxine (B6)	Folic Acid (B9)
Cruza	73.21^{a}	6.73^{ab}	289.25^{ab}	ND^{a}	150.56^{b}
Kachpot1 (CIP 382171.4)	59.03^{a}	6.59^{a}	216.85^{a}	92.73^{cd}	132.14^{b}
Kimuli	65.76^{a}	7.22^{b}	229.52^{ab}	92.43^{cd}	124.86^{b}
Kinigi	59.81^{a}	6.73^{a}	226.80^{ab}	58.63^{b}	143.35^{b}
Mbumbamagara	172.78^{b}	6.59^{a}	221.31^{ab}	100.08^{d}	ND^{a}
Rutuku (CIP 720097)	55.78^{a}	6.58^{a}	261.14^{ab}	81.69^{bcd}	151.98^{b}
Rwangume (Naropot4)	52.60^{a}	6.59^{a}	257.45^{ab}	92.72^{cd}	118.53^{b}
Rwashaki	71.00^{a}	6.56^{a}	202.19^{a}	71.52^{bc}	128.11^{b}
Victoria (CIP 381381.20)	63.20^{a}	6.71^{a}	307.38^{b}	111.57^{d}	136.46^{b}

Values are means in µg/100g. Figures in a column with the same superscript are not significantly different ($p > 0.05$). ND = Not Detected

The effect of processing treatments on acrylamide concentration of French fries processed from the different potato varieties are summarized in Figure 9. The results indicate that the size of the strips and heating regime (time-temperature combination), as well as the genotype, had a significant effect on the acrylamide content of the French fries. Largely, French fries with a smaller thickness (10x10 mm) recorded the highest increase in acrylamide content under high temperature-short time regime (HTST). Rwangume produced French fries with higher acrylamide content (211.7 - 812.7 µg/Kg) under all the processing conditions compared to the rest of the varieties. The lowest concentration of acrylamide (144.5 µg/Kg) was recorded in *Kachpot1* of 10x10 mm thickness and blanched at 70^{o}C for 10 min.

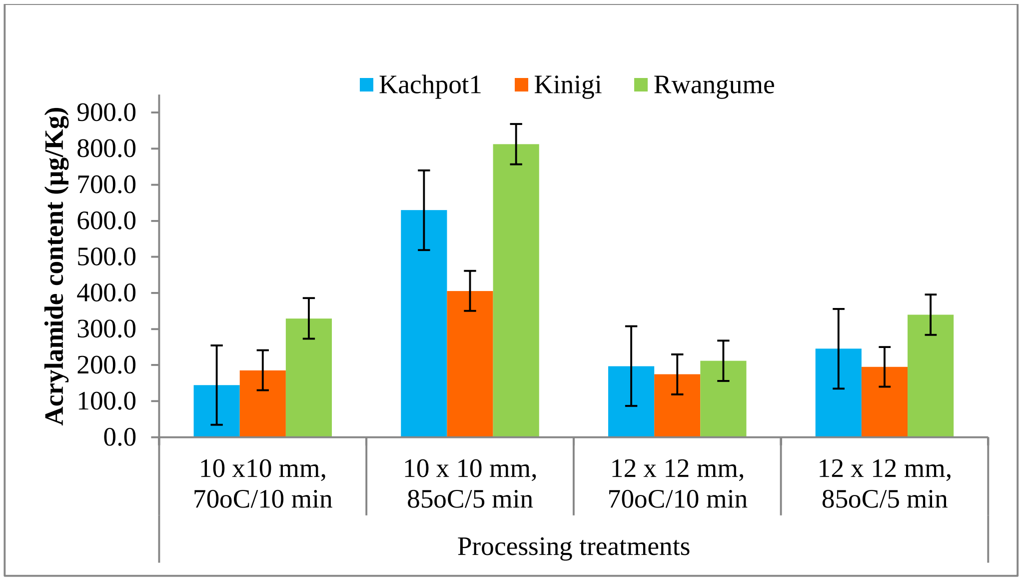
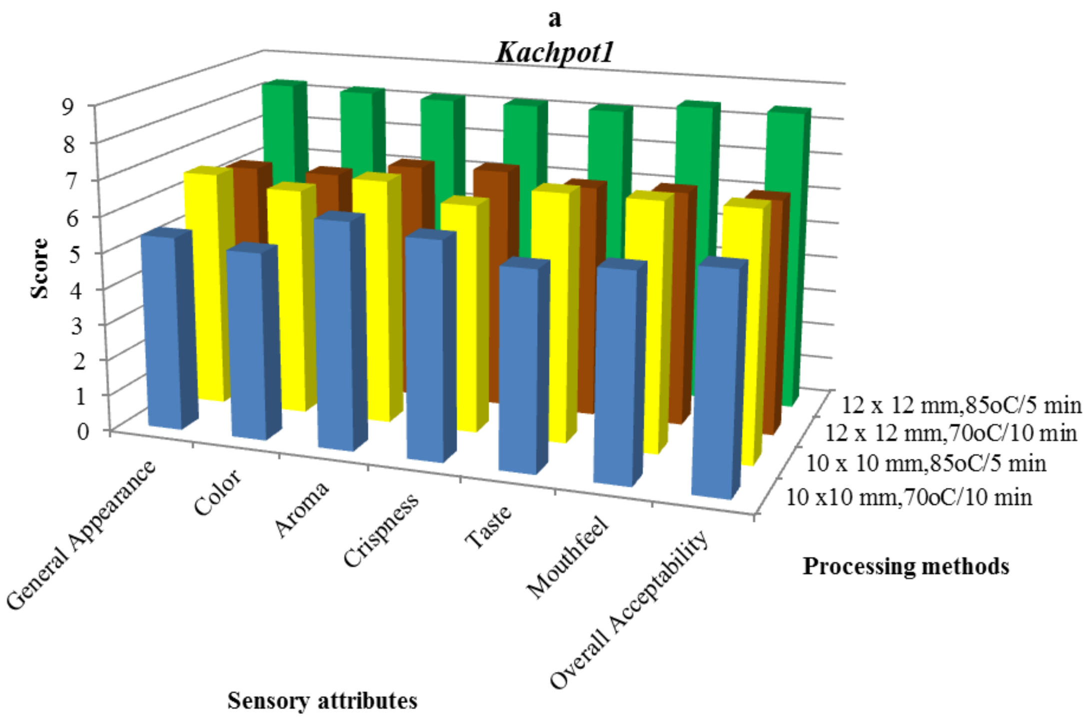
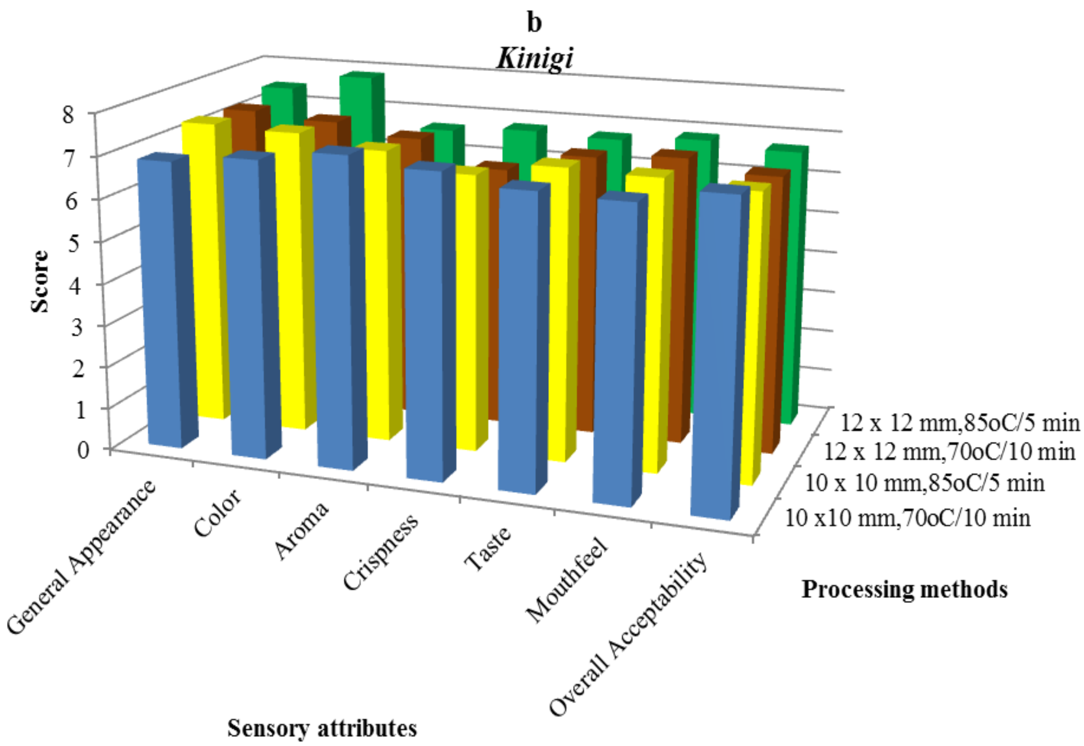


Figure 9: Effect of processing treatments on the acrylamide content of French Fries

The processed French fries were scored for their general appearance, colour, aroma, crispness, taste, mouthfeel and overall acceptability on a 9-point hedonic scale ranging from 1 to 9 (where Scores: 1-Dislike extremely, 2-Dislike very much, 3-Dislike moderately, 4-Dislike slightly, 5-Neither like nor dislike, 6-Like slightly, 7-Like moderately, 8-Like very much, 9-Like extremely). The results indicate that the genotype, the size of the strips and heating regime (time-temperature combination) had an effect ($p<0.05$) on the sensory attributes of the French fries. *Kachpot1* yielded the highest score (8.1-8.4) for most of the sensory attributes (Figure 10). Moreover, high temperature-short time (HTST) regime produces French fries of higher sensory attributes scores and this was more pronounced in French fries with thicker strips.


a
Kachpot1
Score
9
8
7
6
5
4
3
2
1
0
General Appearance
Color
Aroma
Crispness
Taste
Mouthfeel
Overall Acceptability
Sensory attributes
12 x 12 mm,85oC/5 min
12 x 12 mm,70oC/10 min
10 x 10 mm,85oC/5 min
10 x10 mm,70oC/10 min
Processing methods


b
Kinigi
Score
8
7
6
5
4
3
2
1
0
General Appearance
Color
Aroma
Crispness
Taste
Mouthfeel
Overall Acceptability
Sensory attributes
12 x 12 mm,85oC/5 min
12 x 12 mm,70oC/10 min
10 x 10 mm,85oC/5 min
10 x10 mm,70oC/10 min
Processing methods

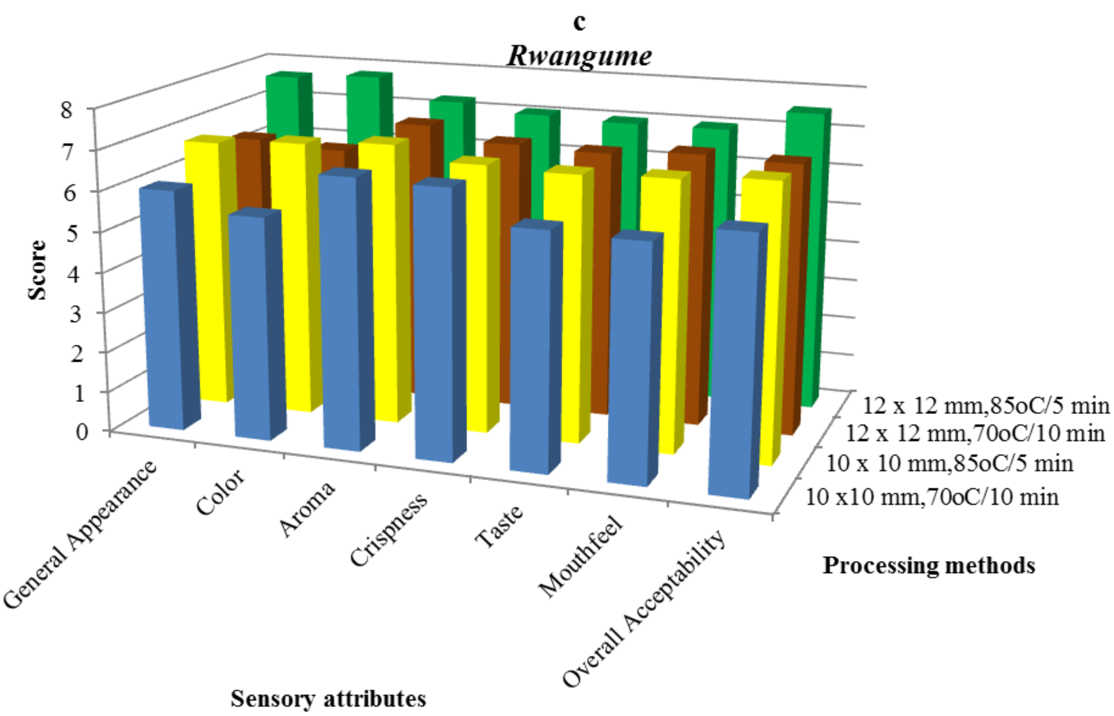


Figure 10: Effect of processing treatments on sensory attributes of French fries

The results of this study revealed that majority of potato varieties commonly grown in Uganda have high dry matter content (>20%), with tubers that are medium in size (50-60 mm), round in shape with medium eye depth. *Kachpot1*, *Kinigi* and *Rwangume* are the suitable varieties for processing French fries due to their low reducing sugar (less than 0.50g/100g FW), high dry matter, shape, eye depth and size of the tubers. Slicing at 12x12 mm and blanching at 85^{o}C for 5 min was found to be the suitable pre-processing parameters for producing the most acceptable French fries.

Since only three varieties (*Kachpot1*, *Kinigi* and, *Rwangume*) have the most suitable traits for processing into French fries, seed breeding and multiplication program at KAZARDI should focus on enhancing the production and productivity of these varieties. Deliberate efforts should be put in place to improve the postharvest handling and storage of these varieties to reduce the postharvest losses and ensure the quality meets the requirements of the French fries industry. There is need to popularize and promote these varieties among restaurants and hotels as the most suitable varieties for processing French fries.

The Project undertook other studies aiming to develop a variety of value added products from potato as a remedy to the high postharvest losses farmers face, and providing a wider variety of products to the consumer, whilst increasing the incomes of the value chain actors especially the farmers. One pathway the project used was production of potato flour, and subsequently other products using the flour as the main ingredient.

Two treatments were set, one with peeled potato tubers and another one with unpeeled tubers. The experiment tested the effect of peeling on the quality and quantity of potato flour produced. Lab analysis were performed to establish the effect of diverse factors (peeling and heat treatment) on the proximate composition of the flour as well as the consumers' acceptability of the product.

The Project installed solar driers in which the sliced potato tubers were dried. The dry chips were milled to get the final potato flour.






The results show that the production of potato flour is economically and physically viable, and the flour has good characteristics that make it a suitable intermediate product for production of much higher value food products.

The Project used the potato flour to develop a variety of products including bread, cakes, cookies, biscuits and chapatti. One student of MSc Technology, Innovation and Industrial Development at Makerere University, Anthony Kwehangana, determined the potential of flour processed as an ingredient for food processing industry. His Thesis title is "***Production of Irish potato flour as a potential ingredient for food processing industry***".

Kwehangana identified and selected six potato varieties (Rwangume, Kinigi, Victoria, Rwashaki, Rutuku and Cruza) and assessed them for production of flour using physical tuber characteristics of shape, size, eye depth, skin, tuber flesh colours, and moisture content. Tuber shape, skin colour and fresh colour were determined visually, while moisture content was determined by adopting Association of Official Analytical Chemists, AOAC (2004) method. Sensory evaluation was also done to determine the acceptability of flour developed from the identified varieties.

The tubers were washed in running tap water to remove any adheringsoil, dirt and dust and then peeled and sliced thinly into a 5mm thickness using an electrical cutting machine (model CL55). The slices were washed under running tap water and soaked in two volumes of 0.3% potassium metabisulfite for 2 minutes.

Potato processing equipment; peeler, slicer & drier

The sliced tubers were dried at 75°C for 5 hours using a static electrical dryer and for 12hrs using a solar dryer to obtain the desired moisture content of 13%. The dry slices were milled using a motorized hammer mill and sieved through a 250μm diameter mesh to obtain fine flour of uniform size. The flour was packaged in polyethylene bags and stored at room temperature for further analysis. The process is summarised in Figure 11.

The potato and potato flour were analysed for moisture, ash, fat,protein and carbohydrate. Moisture, fat and protein contents were determined by adopting Association of Official Analytical Chemists, AOAC (2004) method.

The flour was used to develop chapatti and biscuits**.** The basic ingredients of different types of chapattis (CHO, CH1, CH2, CH3, and CH4) with various proportion of wheat and potato flour were used. (i) the flour was mixed with salt, baking powder and then mixed with water to prepare dough. (ii)The dough was then divided into four equal portions, rounded and rested for a couple of minutes, sheeted to a flat and round shape upto thickness of 2.5 mm and cut out with a round chapatti cuter of 10.5 cm diameter. (iii)The chapattis were prepared from a preheated non sticky frying pan.

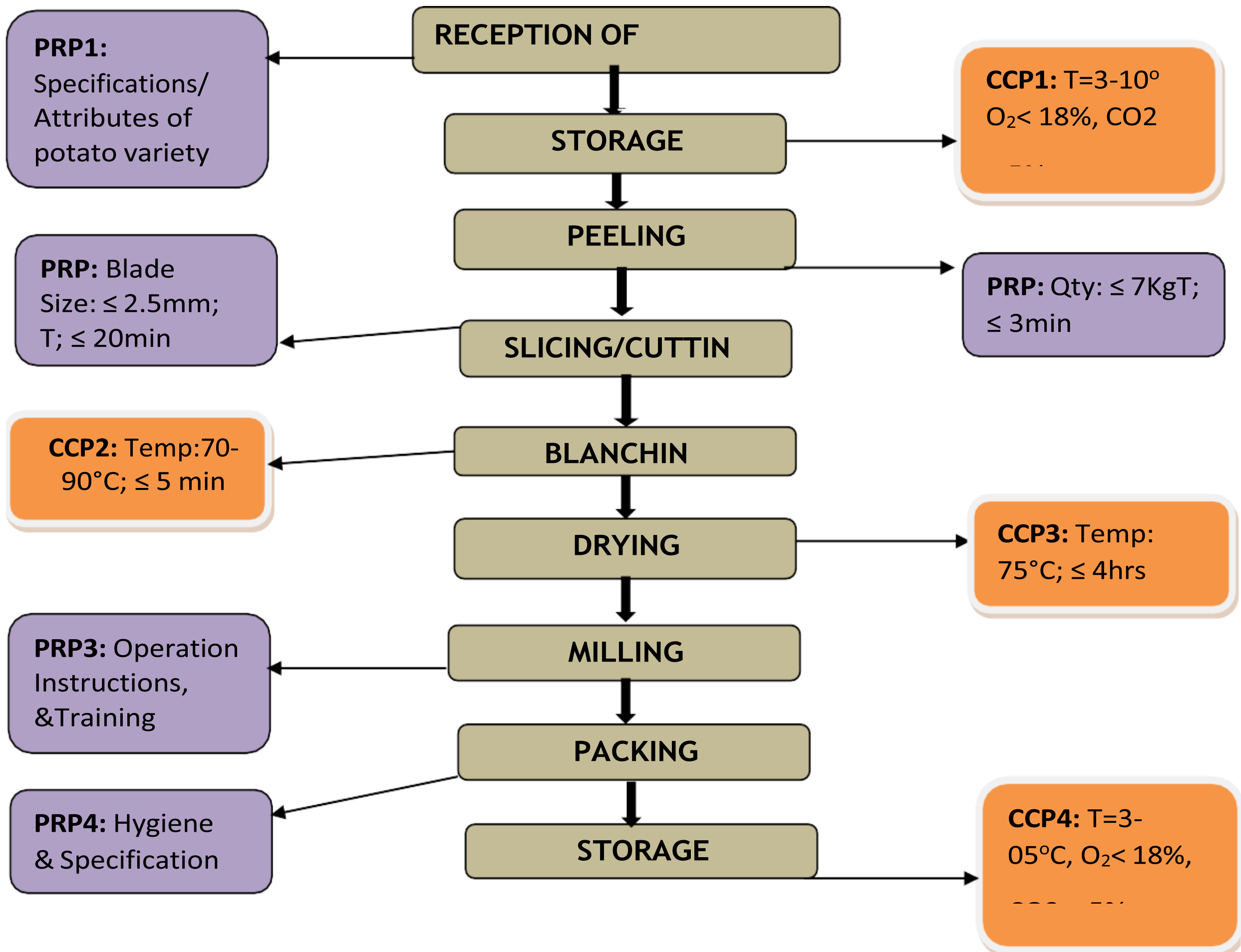


Figure 11: Process flow for production of potato flour

The basic formulations for biscuits preparation were opted. All the ingredients were weighed accurately. (i) The pre-weighed flour, sugar, salt and bakingpowder were mixed thoroughly. (ii) Then shortening and egg were added and mixed properly to make adequate dough and kept rest for a while then the dough was rolled to a uniform sheet of thickness. (iii)The sheet was then cut according to the desired shape and size of biscuits with a cutter and baked in the oven at 210^{0}C for 8 min, cooled to ambient temperature and packed in plastic bags.

Potato flour was incorporated in the traditional recipe to replace refined wheat flour at levels of 10, 20, 30 and 40 percent in preparation of biscuits. Biscuits were produced from the four formulations using the method described (Manley, 2001). The biscuits were prepared from various combinations of potato flour and wheat flour in ratio of 100:0(SO),90:10 (S1), 80:20 (S2), 70:30 (S3) and 60:40(S4), respectively. The standardized formulations for biscuit hadingredients as 100 g flour, 45g sugar, and 45g hydrogenated fat, 1.25g sodium bicarbonate, 1.25gbaking energy. The biscuits were allowed to cool for 30 minutes and stored in airtight plastic container before further analysis.

Sensory evaluation scores for general acceptability of the Chapattis formulations were significantly different ($p \leq 0.05$). The scores for general acceptability of CH1 (8.34), CH2 (8.36), CH3 (7.79) and CH4 (7.78) were lower than for the control experiment chapatti CHO (8.49). Chapatti sample incorporated with 40% potato flour CH4 (7.78) had the lowest scores for acceptability because of the dark colour. General acceptability for CH1 (8.34) and CH2 (8.36) were not significantly different ($p \geq 0.05$) from the control CHO (8.43). The scores for CH2 (8.36)incorporated with 20% potato flour were higher than for other samples apart from the control experiment most probably because their general appearance, flavour taste and texture were like more than for the control sample.

For the biscuits, sensory evaluation showed that the overall acceptability limit was 100% up to the level of 30% incorporation. But a declining trend in the level of acceptability from extremely acceptable to moderately acceptable was observed when the level of potato flour incorporation was increased from 0% to 40%. Control biscuits (0 percent potato flour) had the highest score for all the characteristics, however scoresat 30% potato flour levels were found acceptable for all the sensory characteristics. But there was a significant drop in acceptable level which was observed at 40% potato flour incorporation for all the sensory attributes. Scores of the other sensory attributes like flavour, texture and taste also revealed that acceptability level of the respondent was higher for the 30% incorporation level.

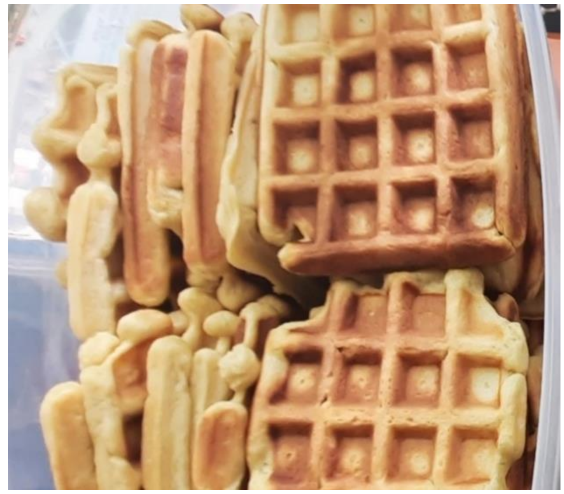
The study concluded that potato varieties of Rwangume, Kinigi and Rutuku have good physical tuber qualities, high dry matter and are suitable for processing into Potato flour. It was established that it is economical to develop potato flour as a potential ingredient for food processing industry through appropriate processing steps. Moreover, processing does not have any adverse effect on nutritional proximate composition of the potatoes. Nutritional composition of raw potato tubers and potato flour demonstrated an excellent nutritional profile that present an interesting nutritional composition, with protein, ash, fat and moisture content which suggests a great technological quality and viability of flour incorporationin several kinds of food products as composite or fortified or as a potential ingredient inprocessing industries. Potato processing and value addition can, therefore, be harnessed without adverse effect on nutritional quality composition and consuming processed potatoes supplies adequate nutrients required by the body. The flour can economically be used as a viable product e.g. as a thickener and colour or flavour improver or used as a potential ingredient in the manufacture of bakery products.

5.2 Market potential and profitability of the potato value added products

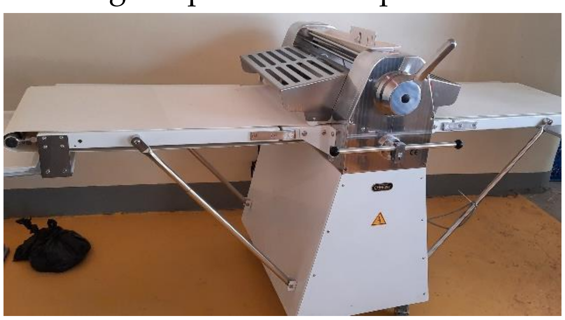
Due to cumulative and inter-connected effects of poor quality seed, lack of fertilizers and pesticides, incidence of pests and diseases beside other inadequate agronomic as well as land scarcity, potato yield has decreased with production of more and more small tubers unsuitable for the market. In most cases, farmers use these tiny tubers as seed to minimize their losses, and this amplify the problem instead of resolving it. To address this challenge, the project developed and tested innovative potato-based value added products using the non-marketable tiny potato tubers.

The results show that the production of potato flour is economically and physically viable, and the flour has good characteristics that make it a suitable intermediate product for production of much higher value food products. In fact, about 20kg of flour are processed from a bag of 100kg of tiny potato tubers. The flour is then packaged in 1kg and 2kg packets for further use.

To make the potato flour more profitable, the project processed cookies, biscuits and waffles using the flour. The prototypes were presented to a random panel of potential consumers in order to collect their appreciation. Majority of panellists liked the products.



The Project got supplementary funding from the Government of Uganda through Makerere University Innovation Fund to further develop the porotypes to a commercial level. The funds (UGX393,818,000) were used to do further research on optimizing the production of high quality potato-based products, determine the socio-economic prerequisites for commercializing the developed prototypes, and procure equipment for processing the potato-based products.



To determine the commercial potential of the processed potato-based products, the project conducted market studies in various urban areas”. On this activity, one MSc student of Agribusiness Management at Makerere University, **Bridget Nantambi**, is writing MSc Thesis titled, “***Consumer acceptance and willingness to pay for potato -based products: A case of urban consumers in South-western Uganda***.

Although the production of the potato-based products was found technically feasible with positive results from sensory testing, the question remained whether the products could profitably penetrate the market, and whether they would be accepted by consumers given the many competing wheat-based products which already had established some market position.

Nantambi’s study therefore determines consumer acceptance of the potato-based baked products and their competitiveness in the market. Using the potato-based cookies, she specifically profiles the potential consumers for the product, determines the factors that influence consumer acceptance of and willingness to pay for the cookies, and determines market competitiveness of the products.

A market/consumer survey was conducted in South-western Uganda targeting consumers in Kabale, Kisoro, and Mbarara urban areas. This area was purposively chosen because Kabale and Kisoro, potato is a major food and cash crop and the people in this region are potato traditional consumers. Their perspective in appreciating processed products from raw potato tubers was assumed to be different from that of the non-traditional potato consumers. On this basis, Mbarara which is the nearest large urban area was also chosen to represent the non-traditional potato consumers.

Using a contingent valuation method, a pre-tested structured questionnaire was administered to collect socio-economic characteristics of the respondent, consumer perceptions on the attributes of the cookies including size, colour, shape and taste (mouth feel, crunchiness and sweetness), the quantity they would be willing to purchase and the price they would be willing to pay. Cheap talk (CT) was used where respondents were first informed about the product composition. This was followed by signing on the questionnaire as a way of consent before tasting and answering any questions. Primary data were collected on the general respondent information, socio-economic characteristics, income, confectionary purchase behaviour, product attributes, prices the respondent was WTP. Consumers were asked to compare their most desirable attributes and the reasons for their choice based on a four-point Likert scale (4=strongly like, 3=like, 2=Dislike, 1=strongly dislike).

Results show that the potato-based cookies were highly acceptable/preferred (by all the potential consumers) across different consumer segments (age, income, education, gender). Majority of the consumers (51.3%) considered taste of the product as the most important determinant in deciding the cookies to buy (Table 12).

Table 12: Ranking by consumers in making choices to buy the new cookies in South-western Uganda

Attribute	Consumers (%)	Attribute	Consumers (%)
Taste	46.8	Shape of cookies	10.0
Price	26.3	Pack size	9.3
Mouthfeel	18.3	Expiry date	8.5
Piece size	17.3	Brand name	8.2
Colour of cookies	12.4	Cookies appearance	7.8

Consumers were willing to pay a price above breakeven point (20-35% above cost of production), and the price they were willing to pay gave the cookies a favourable competition with similar products on the market.

Consumers were willing to pay about 1,610 Uganda shillings (US$ 0.46) per pack of 100 grams of potato-based cookies. This is an indicator of the likely market entry success given that the producer would breakeven by selling the cookies at 1,000 shillings (US$ 0.29). Prices of close substitutes (other cookie types and biscuits already in the market), and the distance where cookies are bought, are the key factors that significantly influence the price consumers would be willing to pay for the potato-based cookies (Table 13).

Table 13: Factors influencing the price consumers are willing to pay for potato-based cookies

Variable	Coefficient	Std. Error	p-value
Constant (in Ugandan shillings)	1,610.626	307.103	
Price of cookies consumers currently buy	0.231	0.052	0.000
Price of biscuits consumers currently buy	0.092	0.044	0.038
Average quantity every time the consumer buys	-1.667	1.267	0.189
Distance where cookies are bought	0.260	0.128	0.043
Consumer's age (years)	0.513	6.598	0.938
Consumer's education level (years of schooling)	6.245	15.056	0.679
Attributes considered when buying cookies	0.622	23.762	0.979
Model	R^2 = 0.135	Adjusted R^2=0.108	F = 5.13***

The study concludes that taste, shape, colour, mouth feel, appearance, piece size, brand name, and packaging material are the attributes that consumers consider while purchasing cookies. The developed potato-based cookies have attributes comparable to their close substitutes already in the market, but consumers have a higher preference to the former. Selling the potato-based cookies in places/markets closer to consumers increases the price consumers would be willing pay for them.

Resulting from the above project activities including the training of potential entrepreneurs two business companies owned by the graduate students on the project were created. They adopted processing and commercialisation if potato-based products, employing 11 workers and sourcing potato tubers from over 100 farmers. One company, Muhingi Products Ltd, produces and sells waffles, cookies and *daddies* from potato, sweet potato and other crops locally available. The products have low sugar levels and very low levels of gluten while others are gluten-free. They are rich in dietary fibre, potassium, calcium, iron, zinc, and vitamins A and C.

6. Human resource development for research and sustainable development of agricultural value chains

The potato CARP+ Project developed human resource largely at three levels; farmer, TVET level (staff and students), University (BSc. Interns, MSc and PhD students), researcher and entrepreneur (food processing) level.

6.1 Farmers and farmer groups

The Project set up farmer field demonstrations in Mbarara, Kabale, Rubanda and Rukiga districts as learning sites for farmers and other interested stakeholders. In agreement with the communities and farmers, the selected demonstration sites were easy to access by the target group. In these fields best bet crop intensification technologies and practices were demonstrated and trainings in good production and postharvest practices were offered. One of the most successful Farmer Field Demonstration was set up at the Diocese of Kigezi because of the number of people that would access it and also because of the commitment of farmers and the ease of access by a wide community. This arrangement impacted on 3 farmer groups (each of about 33 farmers) who directly participated in running the demonstrations. The approach was so cost-effective that other non-group farmers totalling to over 1,729 farmers were reached through different project activities.

The trainings were held at the respective field demonstration and experiment sites of the project. The trainings were open to all farmers whether in the formed groups or not. It was also open to all categories of farmers, whether potato growers or not, and whether one was from within or outside that community. The setup of the trainings was a blend of classroom environment and going to the potato gardens for practical sessions. The topics covered agronomic practices for potato, value addition and marketing.

Agronomic practices

- Site selection
- Seed selection
- Land preparation
- Planting and spacing
- Fertilizer application
- Seed potato tuber placement
- Converging
- Weeding and earthing up
- Disease management
- Late and early blight
- Dehaulming
- Harvesting and storage

Value addition and process

- Potato crisps production using appropriate technologies
- Potato flour production using appropriate technologies

Potato marketing

- Pre-market preparations and market strategies
- Types of market information needed
- Accessing market information
- Collective marketing

The training team/facilitators comprised of Scientists from Kachwekano Zonal Research and Development Institute and Makerere University, partner staff from Excel Hort Consult and Uganda Industrial Research Institute, and the Graduate students on the Project.

During a training session at Excel Hort Consult, at Biharwe, Mbarara site

Participants observing a well-managed potato garden at Rukiga site

Participants during a theory session at Rukiga site

Participants attending a theory session at Rugarama, Kabale site

Apart from the farmers, the demonstration sites were also frequently visited by students from secondary schools and tertiary institutions, government officials especially from the Operation Wealth Creation (OWC).

Government officials from OWC and secondary school students at Excel Hort Consult, Mbarara site

Training farmers on potato harvesting

6.2 Inclusion of TVET Institution

The potato CARP+ Project involved Bukalasa Agricultural College, a TVET Institution located in Luwero district. This Institution was selected for three reasons: 1) it trains agricultural Mid-Level Cadres at Diploma level who, after graduation, directly work with the agricultural communities; 2) it practices outreach to smallholder farmers who are targeted by the project; 3) it is located in proximity to Makerere University. The project team identified and involved academic staff in the Departments of Crop Production, Horticulture and Agribusiness Management. In collaboration with these staff, students to participate in the project were selected. The selection considered academic programs in which the students were enrolled and gender of student (females and males).

TVET students participating in field trials for testing systems of potato intensification under the CARP+ potato value chain project. ***a – f*** *Makerere University postgraduate and undergraduate students work with TVET diploma students to establish trials.* ***g*** *and* ***h*** *Makerere University students, TVET students and KAZARDI scientist work with farmers in south-western Uganda to establish field trials.*

As a partner, the TVET contributed to two of the project objectives: developing and testing a system of potato intensification (SPI) that optimises farmers' resources whilst increasing productivity in South-western and Central Uganda, and supporting human resource development for research and sustainable development of agricultural value chains. The TVET provided land for hosting project trials and selected students and staff to participate in the project. In 2018, the first cohort of 25 students (10 females and 15 males) drawn from Diploma in Agriculture and Horticulture classes participated in the project activities.

In participating, the TVET students worked very closely with three postgraduate (MSc) and two undergraduate students of Makerere University. While most of the activities they participated in were done at the TVET campus, the students also had the opportunity to participate in data collection and farmer training in four other trial sites in South-western Uganda in the districts of Mbarara, Kabale, Rubanda and Rukiga. Testimonies of the first cohort in the project are captured in the testimonies below:

Ms Faith Natumanya: "During the Project I learnt how to design a field experiment,

layout and mark the design in the field. I also learnt the recommended spacing of potato, which is 75 cm × 30 cm. Before participating in the project, I thought that potato is grown using any spacing as at Bukalasa Agricultural College (BAC) most people do in their farms. I also learnt the different potato varieties including Rwangume, Victoria, Kimulli and Kinigi. With this knowledge I can now easily identify the varieties by the flowers or even the skin. I learnt how to collect data for different plant parameters and how to enter the data into the data sheets. I learnt how to identify different diseases both in potato and in beans. I also learnt that the recommended size of seed potato to grow should be about the size an egg but not the very small size as I have always known. After the project I was greatly motivated and I wrote a project proposal under Techno serve about growing potato for seed as a business which I intend to set up in my home area in Bushenyi district. The main objective of my proposed project is to solve the problem of seed potato since most farmers who grow potato in Bushenyi either buy any potato of unknown quality from the market to use as seed or even use their own-saved poor quality tubers as seed. I also intend to demonstrate to farmers in my home area that potato has a recommended spacing just like most other crops they grow."

Mr Ivan Okumu: "As one of the first 25 students of BAC to participate in the potato value

chain project, I handled the establishment and management of field trials at BAC, data collection and training farmers at different trial sites on potato and bean agronomy. The participation in the research project has enabled me to establish different field trials. I am presently trying to determine the best intercropping plant arrangement for maize-bean intercrop at my home village. I am only able to do this on the basis of the knowledge and skills I acquired from participating in the project. Interaction with different field staffs like from research station Kachekwano Agricultural Research and Development Institute (KAZARDI) and a private agribusiness incubator (Excel Hort Consult Ltd) in Mbarara has made me share field experiences. Interaction with local farmers from different districts and cultures has greatly improved my extension service skills. It has made me believe I can work in any part of the country with different cultures and languages from mine. Movement to different districts also made me to explore different parts of the country. As the student leader for the first 25 students of BAC to participate in the project, I managed to gain leadership skills. With the above experiences from the research, I appreciate the existence of the project and the project leaders for giving Bukalasa students such opportunity for changing their mindset and getting different experiences as far as agricultural production is concerned."

Ms Rovensio Ahimbisibwe: "My participation in the project enabled me to know that

potato and beans or maize can be intercropped. This was by participating in the project research activities and also by observing activities in the farmers' fields in many of the trips I made to the major potato growing areas of Uganda especially in the greater Kabale district. I also learnt how to plant potatoes using the different types of seed beds (either ridged or flat beds) as well as fertilizer placement technique. I had been theoretical taught about diseases and pests of crop plants like potatoes at the college, but my participating in the potato project allowed me to have an actual experience in identification of diseases and pests in the field. Participating in the project also allowed me to interact with different people including students and staff of Makerere University, scientists and technicians from NARO (KAZARDI), staff of Excel Hort Consult I Mbarara and farmers in the different parts of south-western Uganda."

Mr Sunday Mungu Jakisha: As a student who had participated in the Project, I was

trained on how to collect data on different parameters. The Project exposed me to different groups of farmers that we trained on how to manage potato plants right from planting to harvesting. The project enhanced my ability on potato agronomic practices that were done during the project in order to produce high quality products. The project also enabled me to improve on my communication skills during the training of the farmers in the districts of Mbarara, Kabale Rubanda, and Rukiga. As a person who had never been involved in potato growing, now I can grow it without any reason to worry because I have learnt a lot from the project. I have been able to transfer the skills and knowledge got from the project to my half acre plot of potato at my home village in Zombo district that will generate income for me. Thanks for the project because it has helped me a lot."

The CARP+ Project strengthened its partnership with the TVET (Bukalasa Agricultural College) when implementing a Technical Skills Development Programme (TESDEP), Grant No. RU/TESDEP/2020/05. The project objectives were to (i) create higher economic value from potato and commercialize the products for increased productivity and incomes of the value chain actors; and (ii) skill the youths and build their entrepreneurial capacity targeting TVET students who by their background are trainable and innovative to develop and commercialize high value products from potato.

The TESDEP has a business/innovation part and a capacity building component which was in line with the CARP+ Project objective of processing innovative potato based products and commercialization of promising and successful products. The CARP+ project had already developed and tested at lab level different potato based products but had been also providing additional support in developing other potato value-added products. The capacity building component was aimed at skilling TVET students from Bukalasa Agricultural College in food product development and marketing strategies with bias toward processing and commercialization of potato value-added products. A 4-day training was conducted at Bukalasa Agricultural College to equip the selected students with required knowledge and skills for product development and marketing of project outputs. There was also a need to process the different promising potato value-added products for market testing and piloting.

A total of 31 students (20 males and 11 females) were trained in product development and marketing skills of potato. Modules and tools on product development and market skills were designed and used to train students. Training the student on Product Development and Market Skills was done by the team from Makerere University led by Professor Johnny Mugisha. The College offered training facilities (training space, furniture) and project provided logistics.

Training of TVET students at Bukalasa Agriculture College

These students were also involved as market testing and piloting the potato-based produced the CARP+ project had developed. This was done in urban areas close to the TVET campus.

TVET Students preparing samples for market testing under the supervision of Graduate students from Makerere University

The main challenges the project encountered were Covid-19 lockdown that restricted training to small numbers of students. Only students whose homes were near the College were recruited because the College remained closed. Complete closure of schools did not allow the project team to recruit and train another cohort of TVET students. This affected significantly the implementation and completion of all project activities within the work plan as signed in the project contract.

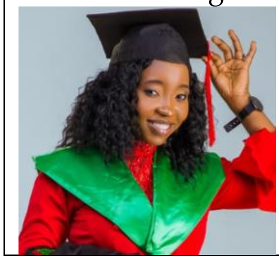
Nonetheless, there were lessons learned. Equipping students with a variety of skills along the agriculture value chain as opposed to the conventional training where students specialised in skills that are in line with their subjects of specialisation. Further, there is a huge unexploited potential among TVET students. They are dynamic and have innovative ideas that need supervision, nurturing and incubation in order to be converted into business products or services. Finally, collaboration between Universities and TVET institutions is key in creation of job and employment opportunities.

6.3 University level (students)

At the start, the project advertised and competitively recruited 3 MSc students (2 females and one male) and one male PhD student. Two MSc students, respectively, focused on objective 1 (*a community-based system/model for farmers to participate in the production, delivery and use of good quality seed potato*) and objective 2 (*a system of potato intensification (SPI) that optimises farmers' resources whilst increasing productivity in South-western Uganda*) of the project. They therefore registered for MSc Crop Science Program at Makerere University. The third MSc student focused on objective 3 (*develop and test innovative potato-based value added products with potential for commercialisation*). He therefore registered for MSc. Food Science and Technology Program at Makerere University. The PhD student work cut across the project objectives, but mainly focusing on objective 2 (*crop intensification*). He registered for a PhD in Agricultural and Rural Innovation at Makerere University. After the second year of the project, a fourth MSc student (female) was recruited to focus on objective 4 of the project (*determine market potential and profitability of the potato value added products and promote market linkages for potatoes and the potato products*). She therefore registered for Master of Agribusiness Management Program at Makerere University. During the course of the project, the project had some balances on the graduate training budget item, and yet there was need for additional studies on objectives 1 and 3 beyond what MSc students 1 and 3 could handle. The flexibility in the budget permitted by RUFORUM Secretariat enabled the project to recruit two more MSc students for a one-year support. One was registered for MSc Crop Science while the other was registered for MSc Technology, Innovation and Industrial Development both at Makerere University. In total, 4 BSc Interns, 6 MSc and 1 PhD students have been trained.

Participating in almost all project activities, they used the project data to write their respective theses. The theses titles are outlined in Table 14. The first recruited MSc students completed and graduated. The other 2 MSc students and the PhD students are in the final stages of thesis writing.

Table 14: Graduate Students on the Project

Student name	Thesis title	Status
Mr. Napoleon Kajunju Bahati Heri (MSc) 	Processing traits of major potato varieties grown in Uganda for potential production of French fries.	Completed and graduated
Mr. Anthony Kyehangana (MSc) 	Production of Irish potato flour as a potential ingredient for food processing industry.	Completed and graduated
Ms. Monica Kigambo (MSc) 	Effect of seed sources, seed tuber size and fungicide seed treatment on the performance of potato in Uganda.	Completed and graduated

Ms. Justine Nakibuule (MSc) 	Response of potato to manipulation of row spacing, fertilizer use and intercropping with beans.	Completed and graduated
Mr. Masiko Mahafuzi (MSc) 	Potato cutting propagation for optimum growth and yield in Kabale, Uganda	Writing thesis
Ms. Bridget Nantambi (MSc) 	Consumer acceptance and willingness to pay for potato-based products: a case of urban consumers in South-western Uganda	Writing thesis
Mr. Rolland Ainebyona (PhD) 	Potato (*Solanum tuberosum*) crop intensification innovation: a case of smallholder farmers in South-western Uganda	Writing thesis

7. Project monitoring, reporting and dissemination

7.1 Project monitoring and reporting

The Project had a monitoring and evaluation strategy that effectively captured, processed, and shared project information and outputs as well as lessons for improvements. The progress and milestones of the project were monitored and evaluated at various levels/phases to ensure proper management and allow for timely corrective measures where there was need.

At the planning phase, the project held a start-up meeting of all the key stakeholders. This brought together all the key project actors. The project objectives, work plans, deliverables and budgets were shared and reviewed. The roles and responsibilities of each partner and individual team member were articulated.

During project implementation, monitoring and evaluation was the responsibility of the entire project team, target group and some key stakeholders, but with overall coordination by the Principal Investigator. Regular reporting was made and meetings held to give feedbacks on the project achievements, on which basis the progress towards the milestones were regularly evaluated.

Each partner and researcher periodically reported on activities accomplished as per the time frame activities planned for the following period, and challenges faced (if any). The graduate students, with support from the project team, would report to their respective supervisors on a monthly basis and bimonthly to the Project Coordinator/PI. The PI compiled the reports from the various team members into quarterly reports submitted to RUFORUM Secretariat. Quarterly and annual reports were submitted. Table 15 shows the project results and activities upon which monitoring was done, while Table 16 summarises the project achievements in reference to what it had proposed at the onset.

Table 15: Project results and activities done

Result	Activities done by the project
Result 1: A cost effective and efficient farmer driven community based quality seed potato production and delivery system established	• A multidisciplinary team (human resource) was constituted as the core project team. • Project meetings, field visits, feasibility studies were done. • Innovation platform was formed and training materials, seed multiplication materials and equipment were procured. • A screen house was constructed and operationalised • Regular monitoring visits and data collection were done at appropriate periods
Result 2: Potato intensification production systems that optimise farmers' resources and increase productivity developed	• Farmers and other key stakeholders in the project area were mobilised and informed about the project and its objectives. • Baseline surveys and community focus group discussions (FGDs) were conducted • Suitable sites for experiments and Farmer Field Demonstrations (FFDs) were selected. • Materials and equipment for the experiments and FFDs as well as for training farmers, were procured.

	• Experiments were set up in the selected sites to establish best bet sustainable crop intensification technologies and practices • FFDs were established by the project team together with the participating farmers and Data were collected at regular intervals.
Result 3: Marketable potato-based value added products developed and tested	• Participants in value addition activities were selected • An inventory of the potato varieties grown the project area was done, and the varieties were screen for processing qualities • Value addition trials were conducted and the promising products screened • Protocols for the promising products were formulated. • Willing potential entrepreneurs were trained to produce and commercialise the products
Result 4: Potential market for potato value added products determined, and market linkages for the products established	• Market surveys for potato and potato products were conducted in Kabale, Kisoro, Mbarara and Kampala urban areas • Market testing for the developed potato-based prototypes was done in urban areas of Luwero, Wobulenzi, Kabale, Kisoro, Mbarara and Kampala
Result 5: Capacity of farmers to increase potato productivity, entrepreneurs to produce value-added products, students to serve communities in agricultural value chains built	• Farmers (in farmer groups) were trained in various aspects of the potato value chain. • Recruited 11 University students (4 BSc Interns, 6 MSc and 1 PhD) and 93 TVET students (in 3 cohorts) • The students were trained and their research and reports were supervised • 35 potential entrepreneurs of the potato-based products were trained

Table 16: Summary of the project achievements

Project objectives	Indicators of achievement	Project achievement
Overall objective: Enhance the capacity of potato value chain actors to reduce the challenges that constrain sustainable potato productivity	• Increased potato productivity • Increased incomes for the value chain actors • Increased value of potato products	• Farmer who have adopted use of quality seed and recommended crop intensification practices have realised increased potato productivity; yield of up to 10t/ha compared to the current 4.2t/ha, and increase in yield of 138% • There is increased availability and accessibility of quality seed, and

		reduced costs of production per unit area • The value of the tiny potato tubers originally non-marketable has increased through processing them into flour, cookies, and other high value products; with a 12-15% increase in the value of potato tubers
Specific objective	**Indicators that show the objective has been achieved**	
1. Design and demonstrate a community-based system for farmers to participate in production, delivery and use of quality seed potato	• Number of farmers and farmer groups producing and distributing quality seed potato • Number of functioning community based systems	• 3 farmer groups (93 farmers) producing quality seed and selling to other farmers • 2 functioning community based systems managed by the farmer groups
2. Develop and test a system of potato intensification that optimises farmers' resources whilst increasing productivity in South-western and Central Uganda	• Number of farmer field demonstrations (FFDs) established • Number of farmers participating in the FFDs • Number of farmers willing to use the recommended potato intensification systems	• 5 farmer field demonstrations established (1 in Bukalasa, Luwero; 1 in Kabale; 1 in Rubanda; 1 in Mbarara; 1 in Rukiga) • 700 farmers participated in the FFDs • Over 70% of the farmers who participated in FFDs were willing to use the recommended practices They realise increased land, capital and labour use efficiency, and increased yields for potato and other crops
3. Develop and test innovative potato-based value added products with potential for commercialisation	• Number of potato value addition protocols developed • Number of potato-based products developed • Number of potato-based businesses incubated	• 7 potato value addition protocols developed (for flour, French fries, cookies/biscuits, cakes, waffles, chapatti, daddies) • 4 potato-based products developed (cookies/biscuits, cakes, waffles, daddies) There is increased number of potato-based products of higher value

		• 2 potato-based businesses incubated (Applied Agribusiness Innovations and Muhingi Products Ltd)
4. Determine market potential of the potato value added products and promote market linkages for the potato-based value added products	• Number of potato-based products market tested • Number of market linkages for the potato-based products established	• 4 potato-based products developed (cookies/biscuits, cakes, waffles, daddies) market tested There is increased number and sales of potato-based products, and increased incomes of potato value chain actors • Over 10 supermarkets in Kampala; 3 markets in Kabale; 4 markets in Mbarara for the developed products
5. Support human resource development for research and sustainable development of agricultural value chains	• Number of farmers and farmer groups trained in quality seed production and delivery • Number of entrepreneurs incubated • Number of students trained and graduated	• 3 farmer groups and about 1,730 farmers trained • 35 potential entrepreneurs trained • Trained students: - 93 TVET students - 4 BSc interns - 6 MSc students - 1 PhD student The capacity of farmers to increase productivity, entrepreneurs to produce value-added products, and students/graduates to serve communities in agricultural value chains was enhanced.

7.2 Dissemination and outreach

During the project period, periodic reports and short-length research outputs (Extended abstracts) were produced and published with RUFORUM websites for wide visibility. In addition, research outputs were presented in various fora including RUFORUM Biennial Conferences; first on 22 - 26 October 2018 in Nairobi, Kenya, second on 06 - 10 December 2021 in Cotonou, Benin and third on 12 - 16 December 2022 in Harare, Zimbabwe. The graduate students also made oral presentations during the NARO-Makerere Joint Scientific Conference (14-16 March 2023) at Speke Resort Munyonyo in Uganda.

During these conferences, oral and poster presentations were made, in addition to exhibition of product prototypes. Other 8 exhibitions have been held in Kampala on various occasions including a TV talk show. Some were held at RUFORUM Secretariat to MasterCard Foundation Delegates, Arab Development Bank Delegates, Uganda Minister of Science, Technology and Innovation and her officers.

The Project sites (the potato processing facility, field experiments and farmer field demonstration gardens) have been serving as visual dissemination avenues. Different stakeholders have visited the sites including Local Government officials, the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) led by the Minister of State for Agriculture, **Hon. Bwino Fred Kyakulaga**, who also officially launched the processing facility of the entrepreneur of Muhingi Products Ltd., and the World Bank delegation that funds the Multi-Sectoral Food and Nutrition Security Project of MAAIF. Others are the King of Tooro Kingdom, His Highness **Oyo Nyimba Kabamba Iguru Rukidi** the 4th. The King was guided by the Prime Minister of Uganda, **Rt. Hon. Dr. Ruhakana Rugunda** and the Minister of State for Finance and Economic Planning, **Hon. David Bahati**.

The King and his delegation visiting the project screen house

The four graduate students who have graduate have each published a Masters Thesis available on Makerere University repository. In addition, they have published some papers in peer reviewed journals and other papers are in manuscript form. The published papers are:

Kajunju, N. Heri Bahati, Atukwase, Abel, Tumuhimbise, Gaston-Ampe, and Mugisha, Johnny. 2022. Characterisation of Potato Varieties Commonly Grown in Uganda for Food Processing Suitability. *African Crop Science Journal*, 30 (1): 51–68. https://doi.org/10.4314/acsj.v30i1.4

Kajunju, N. Heri Bahati, Atukwase, Abel, Tumuhimbise, Gaston-Ampe, and Mugisha, Johnny. 2021. "Potato Processing in Uganda: A Technical Review." *Makerere University Journal of Agricultural and Environmental Sciences*, 10 (1): 60–81

Nakibuule, Justine, Jimmy Obala, Monica Kigambo, N.H.B Kajunju, and Johnny Mugisha, 2022. Effect of potato-bean intercrop arrangement, plant spacing and fertiliser usage on plant growth and tuber yield in different environments. *Makerere University Journal of Agricultural and Environmental Sciences*, 11 (2): 107 - 126

8. Project impact

The project envisaged benefiting potato value chain actors, mainly the smallholder farmers, processors and consumers in Uganda. For wide reach, the project adopted a group approach with anticipation that the farmers who participated in demonstrations and experiments were able to share with others in the group. The participation of farmers has resulted in adoption of optimised potato intensification system, increasing farm resource use efficiency and productivity for both potato and other crops.

The project developed 5 Technologies, Innovations and Management Practices (TIMPs), namely:

- Potato seed production and storage technologies at farmer level
- Potato intensification technologies and practices generated from integrating farmers' and researchers' knowledge
- Production of chilled and frozen potato strips used in processing of French fries
- Production of potato flour from non-marketable tiny tubers - an intermediate raw material for biscuits, cookies, bread, soups
- Production of assorted cookies and waffles from the non-marketable tiny potato tubers

The use of innovative value addition processes has increased the value of potato. A number of potato-based processed products are now available to consumers. The overall impact is enhanced sources of farmer and community livelihoods with increased capacity of potato value chain actors to drive the chain. The project provided business incubation and mentorship to two entrepreneurs to commercialise the developed products. Muhingi Products Ltd. is one the successful stories from these students. Muhingi Products is an SME created by the students on the project. The company processes potato-based products including gluten-free cookies; employs 11 people and collaborates with over 100 farmers to source raw materials.

The project benefited the TVET Institution by skilling 6 academic staff and 61 students. The project brought on board the academic staff of the TVET Institution, who were initially non-research oriented. It enhanced their research skills and strengthened the relationship between the TVET and the University. The inclusion of the TVET was to facilitate learning of agricultural skills and to support closer links with the university.

The students at Diploma and Certificate levels were trained in different aspects of the potato value chain with focus on good agricultural practices and entrepreneurship. The involvement of the students in the project activities together with the training enhanced the spread of agricultural knowledge and technologies.

Other beneficiaries are University students attached to the project. The 11 University students (1 PhD, 6 MSc and 4 BSc Interns), in addition to conducting research within the project framework, undertook facilitation of the farmer learning processes. Since their graduation, the students have been applying the acquired research and theoretical skills to serve the agricultural sector at different nodes of the value chains.

One of the most successful Farmer Field Demonstration was set up at the Diocese of Kigezi because of the number of people that could access it and also because of the commitment of farmers and the ease of access by a wide community. This arrangement impacted on 3 farmer groups (each of 33 farmers) who directly participate in running the demonstrations. The approach was so cost-effective that other non-group farmers totalling to 1,729 farmers were reached through different project activities.

At institutional level, the visibility of the project researchers and Makerere University at large has increased. The government of Uganda has increasing interest in the project, for instance, the government through Makerere University Research and Innovation Fund has provided supplementary funds to expand the crop coverage; and the Multi-Sectoral Food and Nutrition Security Project of the Ministry of Agriculture, Animal Industry and Fisheries has expressed interest in a partnership.

9. Conclusions and recommendation

The potato crop value chain in Uganda can be enhanced for improved livelihoods of the farming communities and other value chain actors through multidisciplinary participatory approaches. An improved seed value chain that enables the farmers to access quality seed and empowers them in seed selection and handling impacts on crop productivity and profitability. Similarly, adoption of optimal crop intensification practices impacts positively on the quality and yield of crop harvests, hence increasing the use efficiency of the scarce farm resources. One viable market linkage for farmers' produce is value addition and processing. Production of high value processed products is feasible and economically viable. The processed products have attributes that are acceptable by the market, and consumers are willing to pay a price that enables the producers to breakeven. Commercialisation of the products will create backward linkages in the value chain that will impact positively on farmers' productivity and incomes. Although an innovation platform is difficult to implement, it greatly contributes to enhancing the network of the entire project team, the target population and other stakeholder. It helps strengthen the relationship between the University, a TVET and the private sector, mainly the farming community.

To achieve a greater and sustainable impact, the project team recommends longer time and bigger budgets to allow, try and accommodate ideas and innovations that emerge in the process of project implementation. The results that have been achieved by this project need upscaling. Others need follow up and monitoring, for instance, farmer adoption of technologies and practices, and some need commercialisation.

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