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National Semi Arid Resources Research Institute (NaSARRI)
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Contents

Part 4 Conclusions

List of Tables

Part 2

Part 4

List of Figures

Part 1

Part 2

Part 3

Part 4

1 Introduction

1. Research Background

Uganda's economy is heavily reliant on agriculture which accounts for 23.7% of the gross domestic product (GDP). Currently, it is estimated that over 76% of the rural population in Uganda is engaged in agriculture, and the National Development Plan (NDP) III of Uganda recognizes agriculture as a major growth opportunity that is poised to generate employment and positive effects across other sectors. Over the next five years, the agriculture sector in Uganda is expected to contribute additional 1.78% to GDP growth.

In Uganda, agriculture has four primary sub-sectors : crop, livestock, fisheries, and forestry. Among these sub-sectors, the crop sub-sector stands out, and covers root crops, cereals, oil crops, fruits and vegetables or horticulture. However, agriculture crop sector faces challenges of climate change, land competition, poor technologies and policy issues. Moreover, the predominant informal marketing system of agricultural produce contributes significantly to supply scarcities and price volatility of agricultural crops. The expanding population of Uganda projected to double by 2026 needs an efficient, intensified and diversified agricultural system. Therefore, smart farming technologies such as precision farming, greenhouse cultivation, and hydroponics hold promise to revolutionize agriculture in Uganda. In fact, smart farming technology can make agriculture efficient, sustainable and market competitive in Uganda, thereby ensuring a reliable supply for both local and international markets.

However, there is a number of existing barriers to smart farming technology adoption including; limited awareness, technical skills and infrastructure. The aim of the proposed project was to establish smart farm technology distribution for capacity enhancement in functional plant resources production and processing in Uganda. Functional plant resources are plants designed to provide both nutrition and health benefits, including prevention of nutrient deficiencies, protection against diseases, and promotion of proper growth and development. Since there is a well-established link between nutrition and disease prevention, functional plant resources become a significant component to contribute to a healthy lifestyle, rising healthcare costs, increased life expectancy and a health-conscious diet.

Agricultural crop improvement and development programs in Uganda face a number of challenges including; pest and disease, climate resilience, declining soil fertility, low productivity, post-harvest loses, nutrient deficiencies, declining genetic conservation, limited storage facilities, value addition, and innovative research skills. The major impacts of climate change such as changing weather patterns, frequent and severe dry spell, reduced water levels, and increased occurrence of extreme weather events like floods, drought, and increased incidences of pests and diseases experienced has significantly led to reduced agricultural outcomes (McKinney & Wright, 2021). Currently Uganda is ranked 154 out of 165 nations on the Notre Dame Global Adaptation (ND-GAIN) Index 1, making it highly vulnerable to climate change (Dutta & Wunsch-Vincent, 2022). Moreover, the proportion of Uganda's agricultural commodities and products processed is estimated to be less than 5% of products produced.

Nevertheless, Agricultural development through technology improvement and farm digitalization is gradually taking shape in the transformation of farming systems in Uganda. Although the NDP III is advocating for a digitalization agenda of Uganda's agriculture which will benefit the development of smart farming systems as a way of contributing to achieving Ugandan Vision 2040, functional plants lack appropriate policy agenda for their production and processing technologies, with limited research on their functional properties. There is also absence of supportive policies to support funding and research in smart farm technology development.

2. Purpose of the Joint Research

The main purpose of the joint research is as follow:

① To conduct an in-depth analysis of the issues on application of smart farming technology in functional plant resources production and processing in Uganda;

② To analyze the current status and statistics of smart farming technology, suggest policy recommendations for the issues, and promote cooperation between Uganda and South Korea for the development of smart farming technology application in functional plant resources production and processing;

③ To build the capacity of officers and researchers dedicated to the development of smart farming technology application in functional plant resources production and processing in Uganda;

④ To develop a Project Document (PD) to develop an Official Development Assistance (ODA) project that can be supported by MAFRA of the Republic of Korea.

The proposed project is to address critical agricultural challenges and seize opportunities for Uganda's agriculture sector. Smart farming technology is timely as it will optimize resource utilization, enhance yields and mitigate post-harvest losses, improve quality, ultimately boosting food security, rural livelihoods, and export revenue, besides effectively preventing pests and diseases while affording year-round production control.

The project can also lead to establishment of a policy framework that raises awareness, and builds capacities of people in smart farming technology, in addition to empowering smallholder farmers and communities to embrace it. This approach is deemed essential for ensuring the sustainable production and processing of functional resources in Uganda.

Collaboration with South Korea can enrich the project's value by leveraging on their expertise, thus bridging the knowledge gap in Uganda by enabling knowledge transfer, and fostering cross-country learning. Since this project has been aligned with Uganda's economic development goals of improving food security and enhancing export competitiveness, its adoption will ensure a year-round supply of agricultural crops to meet the growing demands of their customer base, thus enhance farm income, promote rural livelihoods, ensure food security, build climate resilience, and manage natural resources.

3. Research Scope

The project focuses on investigating the utilization of advanced agricultural technologies, specifically smart farming to enhance the production and processing of functional plant resources within Uganda. Specifically, the project studied the existing agricultural technologies, challenges faced, opportunities present and policy intervention. It also focused on establishing the potential impact of integrating smart farming techniques in the cultivation, harvesting, and processing of functional plant resources and developed a project for ODA to be submitted to MAFRA in S. Korea.

4. Research Methodology

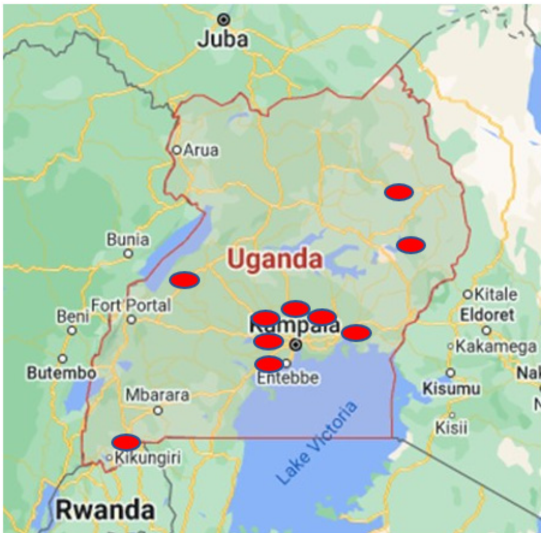
4.1. Study sites and approach

This study was conducted in Uganda at MAAIF, government agricultural research institutions, academic agricultural institutions and health research institution; and private organizations including horticulture farms, agricultural equipment suppliers and agricultural processing. The agricultural research institutions included; the National Agricultural Research Organisation (NARO) covering five national and zonal institutions.

- National Semi Arid Resources Research Institute (NaSARRI)
- National Crops Resources Research Institute (NaCRRI)
- Mukono Zonal Agricultural Research Development Institute (MUZARDI)
- Bulindi Agricultural Research Development Institute (BUZARDI)
- Kachwekano Zonal Research and Development institute (KAZARDI and
- Ngetta Agricultural Research Development Institute (NZARDI)

The health institution was represented by Natural Chemotherapeutics Research Institute (NCRI). NCRI is located within Kampala and its mandate is to conduct research in natural products and traditional methods in the treatment and control of human disease. Currently, NCRI is organized into departments including botany, chemistry and pharmacology.

〈Figure 1-1〉 Map of Uganda showing the study sites



Source: Google maps (https://www.google.co.kr/maps/?hl=ko).

MAAIF is a cabinet-level ministry of the government of Uganda with the mandate to “formulate, review and implement national policies, plans, strategies, regulations and standards and enforce laws, regulations and standards along the value chain of crops, livestock and fisheries”. The ministry is organised into the following department: agricultural planning, animal production & marketing, entomology, crop production & marketing (crop inspection and certification, crop protection, farm development, agricultural infrastructure, mechanization and water for agricultural production), finance & administration, fisheries resources and development, fisheries regulation control and quality assurance, aquaculture management and development, and livestock health & entomology.

NaSARRI is a NARO institute with the mission to foster improved and sustainable integrated crop and natural resources management and specializes in oil crops research, with a particular focus on groundnuts and legumes.

NaCRRI is another NARO institute that encompasses crop improvement and development programs and is actively engaged in researching and cultivating various vegetables including Amaranthus, lettuce, tomatoes, eggplants, garlic, and onions. It also operates some greenhouses projects. NaCRRI is implementing the Farm Income Enhancement and Forest Conservation Programme-Project 2 (FIEFOC-2), aligned with Uganda's National Development Plan (NDP) and Vision 2040.

MUZARDI is the NARO institute responsible for testing (research) and promoting appropriate agricultural technologies, as well as providing the supportive outreach services in the Lake Victoria Crescent Agro-ecological Zone. The institute is involved in project aimed at developing new crop varieties, improving cultivation techniques, and finding innovative solutions to challenges faced by local farmers.

NZARDI is a zonal office for national Agricultural research organization (NARO) with a mandate to carry out applied and adaptive research in all aspects of crops, livestock, fisheries about 300km north of Kampala city.

Kachwekano Zonal Research and Development institute (KAZARDI) is one of the Zonal Agricultural Research and Development Institutes of NARO located in the highlands of Kabale District, South Western Uganda, 450km from Kampala city.

Makerere University Agricultural Research Institute, Kabanyolo (MUARIK) is an academic research institute of the College of Agricultural and Environmental Sciences' School of Agricultural Sciences at Makerere University. The institute serves as the interface between Makerere University and the National Agricultural Research System (NARS), and plays a vital role in advancing agricultural research and technology adoption to improve the agricultural sector in Uganda. MUARIK institute operates various smart farming facilities and research initiatives including greenhouse for efficient crop production.

Feed all Uganda is a private agricultural enterprise that operates two impressive wooden greenhouses for horticulture, each serving as a pivotal component of their agricultural operations. The greenhouses are of different sizes i.e. greenhouse 1 (8 x 20m) and greenhouse 2 (10×12m).

4.2. Secondary data collection

4.2.1. Desk review and data analysis

A comprehensive desk review on the existing literature was conducted in scientific research publications, policy documents and academic theses. The review covered smart farming technology, functional plant resources production and processing, current practices, challenges, opportunities, and technological advancements.

Situational analysis on smart farming technology in Uganda was conducted on agricultural systems. These involved reviewing important publications and reports including bulletins, handbooks, leaflets, audio visual aids (e.g. slide sets, film strips, posters, and photographs). Additional information was obtained from agricultural information centres, exhibitions, farmers' fairs, and mass media (including television, radio, and newspapers).

Furthermore, national policies in government ministries and agencies related to smart farming in Uganda were reviewed. These covered MAAIF, Ministry of Environment and Natural Resources and Ministry of trade and industry. This review covered policy gaps in smart farming technology adoptions.

4.3. Primary data collection and data analysis

4.3.1. Study design, sample size and sampling strategy

The study employed a qualitative approach to collect primary data from key stakeholders. The stakeholder institutions were sampled purposelybased on their involvement in agricultural and health related activities, and their involvement in generating and adapting agricultural technology and innovations, and providing knowledge transfer to farmers through activities such as demonstrations of new agricultural technologies.

4.3.2. Key informant interviews, focus group discussions and observational studies

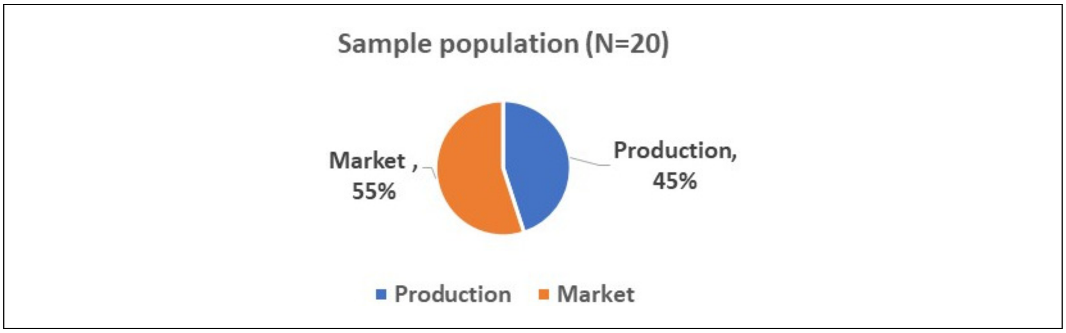
The study also used Key informant interviews (KII) and focus group discussions (FGD) with stakeholders (MAAIF, NARO, private firms involved in agricultural technology provision and local farmers). The KII and FGD interviews were intended to enable the researchers obtain insights, perspectives, and first-hand experiences regarding smart farming technology in the context of functional plant resources production and processing in Uganda.

The KII were conducted in six NARO institutes, one academic agricultural institute, two private agricultural farms, two agricultural input suppliers, agricultural equipment suppliers and two small and medium agricultural processing industries. Each FGD comprised of 6-15 staff scientists, and the discussion focused on applications and potential of smart farming in Uganda, identification of its challenges, and proposition of enterprise crops for smart farming. Observational field visits were also conducted in these organisations to identify the most critical factors in application of smart farming technology in Uganda.

4.3.3. Selection and prioritization of enterprise crop for smart farming

Based on the secondary and primary data, a list of potential enterprise crops was generated through a consensus by the joint research team. The generated list was subjected to validation by the stakeholders through a survey. A semi structured questionnaire was developed and administered to 20 farmers and market vendors within Kampala metropolitan city covering Kampala central, Wakiso and Mukono districts 〈Figure 1-2〉. These districts were selected because of high utilization of the potential crop enterprises. The respondents of the questionnaires were sampled purposely in communities based on their cultivation of the crop (farmers) and sale (vendors). The survey covered the farm production sizes, production quantities and challenges for the farmers while sales volumes and challenges covered the market vendors. The average age of market vendors and farmers were 42.3±18.0 and 44.4±15.4 years, respectively. Females (64%) registered high percentage of respondent for market vendors and males (67%) for farmers. The main occupation of market vendors was business of selling the products and farming for the farmers.

〈Figure 1-2〉 Demographics of the questionnaire respondents (farmers and market vendors)



Based on information generated from the farmer and market surveys, suggested crops (cherry tomatoes, mushrooms, red pepper, beetroot, and turmeric) were subjected to ranking by the research team using a voting method. Each member of the joint research team was assigned to select the three most important crops and rank with the 1st being the most preferred and 3rd being the least preferred in the choice. Each listed crop was awarded marks with the best (1st) scoring 3 and the 3rd preferred scoring 1 mark. Total marks for crops were summed up.

2 Analysis of Current Status of Smart Farming Technology in Uganda

1. Desk Review and Data Analysis

1.1. Situational Analysis of Smart Farming Technology

Smart farming technology (also known as precision agriculture) involves the use of advanced technologies to optimize various aspects of agriculture, including crop production, livestock management, and resource utilization (Karunathilake, 2023). According to Bacco et al. (2019), smart farming is a technology that primarily depends on the use of artificial intelligence (AI) and internet of things (IoT) in cyber-physical farm management. Some of the elements of a smart farming system include the use of : sensors and IoT, Global Positioning System (GPS) and Geographic Information Systems (GIS), drones and Unmanned Aerial Vehicles (UAVs), automation and robotics, data analytics and AI (Artificial Intelligence), and smart irrigation (Karunathilake, 2023; Wang et al., 2021). The recent advances in the Information and Communication Technologies (ICT) domain have the capability to collect, process and analyze data from different sources while materializing the concept of smart farming. The thriving environment for the implementation of different smart farming techniques is justified by a series of technologies that offer the prospect of improving agricultural productivity through the intensive use of data.

There have been many efforts towards the establishment of an automated agriculture framework, capable to control both the incoming data and the corresponding processes. For instance, soil sensors measure moisture, temperature, pH, and nutrient levels to optimize irrigation and fertilization while weather stations provide real-time weather data for better crop management and risk assessment. On the other hand, livestock sensors monitor animal health, behavior, and location for improved herd management while crop sensors measure crop health, growth, and nutrient status through remote sensing technologies. The GPS-guided tractors enable precise planting, harvesting, and field operations while GIS mapping creates detailed maps of fields to optimize resource allocation and identify problem areas. The computer and mobile apps and farm management software provide farmers with tools for monitoring, decision-making, and market access through computers and mobile applications. There is also the use of renewable energy for sustainability for example solar energy for irrigation pumps, electrification, and processing, and the use of agricultural waste to produce biogas (Karunathilake, 2023; Mohamed, 2021; Wang et al., 2021).

The study found that smart farming has grown overtime through integration of science and engineering in agriculture, and innovation and technology development, making it self-automated and highly digitalized (Kohlmeyer & Herum, 1961). A point to note is the use of drones and UAVs for aerial imaging to capture high-resolution images for crop health assessment and disease detection (Abbas et al., 2023; Shahi et al., 2023). The precision spraying, pesticides and fertilizers by drones reduces chemical usage (Abbas et al., 2023; Shahi et al., 2023), improve efficiency, and enhance the sustainability and profitability of farming operations (Karunathilake, 2023).

Therefore, smart farming can really address challenges of food security in Uganda by mitigating the challenges of resource competition, poor technology adoption, and health risks associated with agrochemicals. With Uganda experiencing impacts of climate change, floods and long dry spells, pests and diseases (Fig 2-4) smart farming holds promise to revolutionize sustainable food production by improving efficiency, sustainability, and market competitiveness of agricultural crops. Uganda therefore needs to partner with South Korea to promote the use of smart farming technologies in the country in addition to the many international programs geared towards development agriculture.

1.2. Key Smart Farming Technologies in Uganda

Smart farming technology involves the use of advanced technologies to optimize various aspects of agriculture, including crop production, livestock management, and resource utilization. Some of the existing key farming technologies in Uganda identified include water resource management, soil analysis and management, weather forecasting and climate information, pest surveillance, and greenhouse cultivation.

1.2.1. Water resource management (Irrigation)

This technology assists farmers in overcoming the negative effect of climate change, and plays a crucial role in transitions from subsistence to commercial farming by ensuring year-round production and farm employment. Currently, two irrigation systems are used i.e. sprinkler and drip. The sprinkler irrigation system

(Okuna and Mwesigwa, 2021) allows water distribution through a system of pipes just like rainfall distributes water while the drip irrigation delivers water through emitters of small holes in plastic tubes installed on or below the soil surface directly to the roots of plants 〈Figure 2-1〉.

〈Figure 2-1〉 Sprinkle and drip irrigation system

1.2.2. Hydroponics

This is based on an irrigation system in which balanced nutrients are dissolved in water and crop roots stay in that solution; in some cases, roots can be supported by a medium like gravel (Sharma et al, 2018). Hydroponics have been piloted both singly and in a mixed way, mostly by the private sector in Uganda, especially for the production of common market highly demanded vegetables such as tomatoes and sweet pepper as well as green leafy vegetables for increased profitability, reduced cost of production and efficient use of inputs leading to the sustainable supply of produce. (Gumisiriza, Ndakidemi, & Mbega, 2022). In another study conducted in Uganda and Tanzania in 2021, farmers recommended that hydroponics have the potential to increase food security within urban areas, if more efforts are put in sensitization about the farming system and research into ways to reduce the high costs associated with the technology. Nonetheless, the scalability of hydroponics systems has been slow as it is only seen in a few schools, and urban communities (Gumisiriza et al, 2022).

1.2.3. Soil analysis and management

Although not very common in Uganda, it makes analysis of the farm soils to ascertain the soil nutrients. The soil analysis provides results can guide decision-making on the farm management intervention and provides useful approach for soil fertility monitoring among smallholder farmers to guide soil fertility management. A study on the integration of local and technical knowledge on the classification of soil quality indicators conducted in countries including Uganda provided useful approach for soil fertility monitoring among smallholder farmers to guide soil fertility management (Onyango et al., 2021).

1.2.4. Weather forecasting and climate information

This is important for farmers to access weather forecasts and climate information which help them plan their agricultural activities and make informed decisions. With Uganda's agriculture being predominantly rainfed, farmers have great interest in seasonal weather information, especially the onset and cessation of the rain and dry periods (Tuheirwe-Mukasa et al. 2019). Farmers can use this information to decide on when to plant their crops, weed, and harvest in addition to deciding on what type of crops to plant and what soil conservation practices to put in place, in case of flooding. Usually, the Uganda National Meteorological Authority (UNMA) disseminates weather information to different stakeholders through electronic and print media such as news bulletins on radio and television, email, and newspapers (Tuheirwe-Mukasa et al. 2019). Additionally, the information may as well be tailored as short messages in the form of mobile phone weather alerts short message service (SMS). Currently MAAIF uses the extension services to disseminate agricultural and weather information to farmers.

There is also Grameen Foundation that launched a mobile phone application in Uganda for farmers and offers agricultural advice and targeted weather forecasts

(Balogun et al. 2022). This application offers agricultural advice and targeted weather forecasts to local farmers. Such applications ensure rural farmers in Uganda have access to weather forecast information to support timely farm management decision making, minimizing climate change impacts and promoting sustainable farming.

1.2.5. Pest surveillance

This has been developed as simple and low-cost mobile application to monitor weather conditions and soil health, but also pest and disease thus empowering farmers to make informed decisions in their production system. Some available applications give information on pest surveillance and linkage to market. This therefore informs the farmers to take preventive measures and mitigate crop losses (Dayoub, Nakiyemba, & Plosila, 2021). Simple and low-cost mobile applications have been developed not only to monitor weather conditions and soil health, but also pest and disease thus empowering farmers to make informed decisions in their production system (Balogun et al. 2022). The government of Uganda is in the process of developing models tailored to agricultural context that can give insights and recommendations to farmers, this will support smart farm development (Pedrick, 2019).

1.2.6. Climate smart agriculture

The Food and Agriculture Organisation (FAO) (2010) defines climate-smart agriculture (CSA) as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (greenhouse gases) (mitigation), and enhances the achievement of national food security and development". The CSA technologies being practiced can be classified into five (5) categories:

- Soil and water conservation technologies that include rainwater harvesting, runoff collection and storage, terraces and contours, use of cover crops and mulching;
- On-farm energy technologies like minimum or zero tillage;
- Indigenous and scientific knowledge technologies including use of improved crop varieties that are fast maturing crops and tolerant to extreme conditions;
- Integrated nutrient management technologies such as intercropping with legumes and use of animal waste and
- carbon management technologies such as agroforestry, and fruit tree growing.

CSA promotes the use of appropriate available technologies and practices that are aimed at promoting sustainable production in the agriculture sector. The technologies are targeted towards increased production for both food and income security, but also for mitigating the causes and impacts of the changing climate (FAO 2010). Uptake of CSA technologies is also seen as an opportunity towards reducing greenhouse gas emissions and offsetting the effects of climate change and variability on the agriculture sector (Khatri-Chhetri et al. 2017).

Regionally, according to African Economic Outlook (2017), Uganda is implementing the Comprehensive Africa Agriculture Development Programme (CAADP) Framework (2010), which emphasizes sustainable land and water management for improved agricultural productivity. This is being done through research, technology adoption and dissemination, and agricultural GHG emissions reduction. Uganda submitted its CAADP compact in 2010, and has developed a National Agricultural Investment Plan (NAIP). For example, Uganda has traditional agricultural practices that can be deemed climate-smart, and the Agriculture Sector Strategic Plan has positioned Climate-smart Agriculture (CSA) as a key priority and, if well implemented, position Uganda to benefit significantly from increased implementation of CSA (Radeny et al. 2022).

Uganda has examples of traditional agricultural practices that can be deemed climate-smart, and the Agriculture Sector Strategic Plan has positioned these as a key priority and, if well implemented, it can be increased productivity, resilience, reduces/removes GHGs, and enhances the achievement of national food security and development".

<Figure 2-2> Mulching, contour ploughing, and water harvesting technology in Uganda

1.3. Green House Farming in Uganda

A greenhouse is a system for modification and management of environmental factors that allows plants to be grown in suitable climates that may be not well suited for their growth and development. The greenhouse technology has of recent gained significance due to changing climatic scenarios with emphasis on high quality production along with higher productivity by efficiently utilizing available resources. The productivity and efficiency of green house technology fully depends on the types of greenhouse structure. The type and equipment of greenhouse structure used should generally suit the local environment, availability of construction materials and specific type of crop.

Greenhouses have been established in Uganda majorly for the production of vegetables to enhance productivity and sustainability for urban farming. Some aspects in these greenhouses include; irrigation facilities, precise application of fertilizers and pesticides, use of data analytics for crop performance, prediction of disease outbreaks, and optimization of planting schedules, maximization of space and ensuring year-round cultivation 〈Figure 2-3〉. Besides, there is integration of organic farming practices, recycling of agricultural waste for composting, and the use of renewable energy sources in these green houses.

In Uganda, components such as cover materials, climate-control systems, and irrigation and fertilization equipment are regularly evaluated by farmers and researchers to improve the efficiency of green houses. Since many greenhouse designs are available for a particular crop, it is very essential for farmers to be aware of the advantages and disadvantages of each type and structure. In Uganda, the wooden framed structures span is less than 6m and side posts and columns are made up of wooden materials.

〈Figure 2-3〉 Green house facilities in Uganda

functional plant seedlings	Wooden framed green house at feed All Uganda
	

1.4. Identification of potential functional plant resources under smart farming

The potential enterprise crop categories selected by stakeholders based on their nutritional, medicinal, or/and economic value included; vegetables, nuts, seeds, legumes, mushrooms, and herbs. To be specific, the vegetables that were selected were tomatoes, cherry tomatoes, parsley, cabbage, amaranthus spp, turmeric and garlic/onions. From this list, the FGD of the joint research team came up with priority species that included; turmeric, mushrooms, sparsely cherry tomatoes, red pepper, cannabis, beet root, garlic, onions and spirulina algae. Fermented cereals (rice, millet, corn, barley), mushroom derived products, and other natural sources were also suggested to be enterprise crops. However, a visit to Feed All Uganda and MUZARDI by the Joint research team found cultivation of a diverse range of vegetables, including but not limited to; rosemary, oregano, parsley, lavender, mints, pepper, cherry tomatoes and coriander.

〈Figure 2-4〉 Example of functional plant resources grown at Feed All Uganda

1.5. Importance of function plant resources

Functional plants play an increasingly important role in food security and health due to their abilities to provide nutrition, treat and prevent disease and generate income. For instance, natural bioactive molecules obtained from functional plants can be used in developing novel nutraceutical ingredients which not only promote human health but also aid in improving bio-valorization and the environment as a whole. The recent development of nutraceuticals has generally brought improvements to all aspects of life, including the alleviation of physical disorders, reduction in the use of synthetic antibiotics, and the increase in life expectancy (Li et al. 2017). Moreover, these plants have long been in used are considered safe, effective and sustainable. Nutraceutical ingredients like phenolic acids, flavonoids, tannins, stilbenes, and anthocyanins can be natural antioxidants or free radical scavengers (Nollet &Gutierrez-Uribe, 2018).

Nut continuous use of nutraceuticals is a subject that has received scanty attention, a body of evidence on their importance in both rural and urban people's livelihoods in developing countries like Uganda is growing. It is highly recognized that both cultivated and non-cultivated functional plants are valued and are regarded to combat food insecurity, dietary deficiencies, poverty alleviation (Johnson, 2023: Jiménez Martínez, 2023: Pirzadah & Malik, 2020). While the use of functional plant resources still has an important role in peoples' livelihoods through traditional medicines and food culture, it is important to understand the smart farming technologies that can be used in their production and processing in rural, urban and peri-urban areas all over Uganda.

1.6. Production of functional enterprise crops

A survey conducted among farmers on selected functional resources identified that the current farm sizes for some crops was small. For instance, mushrooms registered plot sizes of 5 x 5ft and 10 x 10ft while cherry tomatoes farm sizes ranged from 0.5-1.0 acres.

The production method for most of functional resources was done in open land, though a few had green houses. For instance, mushroom was mainly produced in small dark rooms. Although cherry tomato was being produced in green houses, majority still produced it open garden.

In the production area, farmers usually monitor some important parameters that are essential for smart farming too. These included parameters like temperature, amount of water, growing media, aeration, source of spores or seed and light(Mushrooms). The cherry tomatoes were majorly monitored for soil type, water, disease and pests, source of seed, temperature and amount of light 〈Table 2-1〉.

〈Table 2-1〉 Parameters monitored during growth of the plants

Enterprise resource	Parameters monitored by farmers during cultivation
Mush rooms	• Temperature • Water/rainfall • Light • Growing medial • Source of seed or spores • Aeration
Cherry tomatoes	• Soil • Water or rainfall • Disease /pests • Source of seed • Temperature • Sun light

The frequency of production of the crops per year is also important, and varied from crop to crop. For instance, mushroom was reported to have at least two per year. Similarly, cherry tomatoes were reported to mature within 2-3 months. The maximum harvested output per season is usually dependent on the farm size. An estimated 1,500kg was reported to be harvested in an acre of cherry tomatoes. However, one very large dark room space of mushrooms could produce up to 600kg. The pests and diseases were also identified to affect harvests. Mushrooms for examples were being affected nematodes /aphids and flies. On the other hand, cherry tomatoes were being affected by birds, Septoria leg spot, early and late blight and nematodes.

The joint research team was also interested in understanding major characteristics of the plant and the farmers. It was found that colour was very essential for mushroom, while both colour and texture were essential for cherry tomatoes.

The challenges experience by farmers in the production also varied from crop to crop. For instance, limited space, expensive spores, theft of the products and limited time to monitor were challenges reported for mushrooms. However, farmers for cherry tomatoes reported challenges like limited market, unfavorable climate/ weather, pest and diseases and birds. They farmers then made a number of suggestions for the challenges that included; harvesting small quantities of crop at a time to avoid overstocking, purchasing materials in bulk e.g. culture/media and spore in bulk (mushrooms), identifying a niche market, provision water sources, use pesticides and growing in green houses (cherry tomatoes).

1.7. Processing techniques of functional plant resources

Currently, Uganda is faced with market and value addition constraints for agricultural products, with an estimated 5% being processed (MAAIF, 2010). These include millet, soya bean, sesame, sunflower, iron bio fortified beans, orange-fleshed sweet potatoes, beet root and tamarind. Millet as one of the common functional foods in Uganda is being processed into fermented traditional alcoholic products referred to as Malwa, Kwete, Mulamba, Entuulire among the different ethnic groups.

Millet is also popular in the production of a non-alcoholic product called Bushera beverage, as flour product (for porridge), and blended product with cassava for preparation of traditional bread called Karo or kalo or atap by different ethnic groups (Kateu, 1998; Adebiyi et al, 2018). The government under Uganda National Bureau of Standards (UNBS) has develop standards for some of these for commercial purposes and for quality assurance. Processing and marketing of millet malt (sprout) is done at the local level to support the traditional brewing of millet beverages (UNBS, 2022)

〈Figure 2-5〉 Examples of processed millet products functional foods in Uganda

Source: https://owinosupermarket.com/products/maganjo-millet-flour.

Although Soya bean is another important functional food product in Uganda, it is mainly processed as animal feed. To a lesser extent, it is processed and blended with other cereals like corn, millet and rice as infant and baby food. Edible vegetable oil is also extracted from soya bean and used singly or as blended with other vegetable oils. Soya bean is also processed as soy milk, soy yogurt and tofu as well as confectionery snacks. The low consumption of soy bean products in Uganda has been attributed greatly to scarcity of its processing technologies and a great deal of it is exported as seed to the neighboring countries (Kemigisha, 2019; Gulkirpik, 2022).

〈Figure 2-6〉 Examples of processed soy bean products as functional foods in Uganda

Source: https://owinosupermarket.com/products/top-snacks-roasted-soya-snacks-product-of-uganda.

Sesame is a functional food product processed by several cottage industries as an edible oil for food and cosmetics (Wara, 2011). The paste from sesame is also blended with ground nut paste as spread on bread and sauce. The existence of national standards for sesame products and raw materials has increased both its local and export market potential.

Beans and orange fleshed potatoes are bio-fortified iron-rich functional products. The government of Uganda has prioritized bio-fortified iron-rich products for addressing nutritional deficiency disorders in the country. Currently, there ara number of cottage industries processing bio-fortified iron-rich beans and orange-fleshed sweet potatoes products in Uganda.

Beet root is also popular as functional food being processed by the cottage industries ready-to-drink pasteurized and fresh beverages, dry beet root powder infusions as well as wines (Tumuhe et al, 2020). Tamarind from the fruits of Tamarinds indica, a wild tree is also being processed into several ready to drink beverage products, and as jam and powder infusion products.

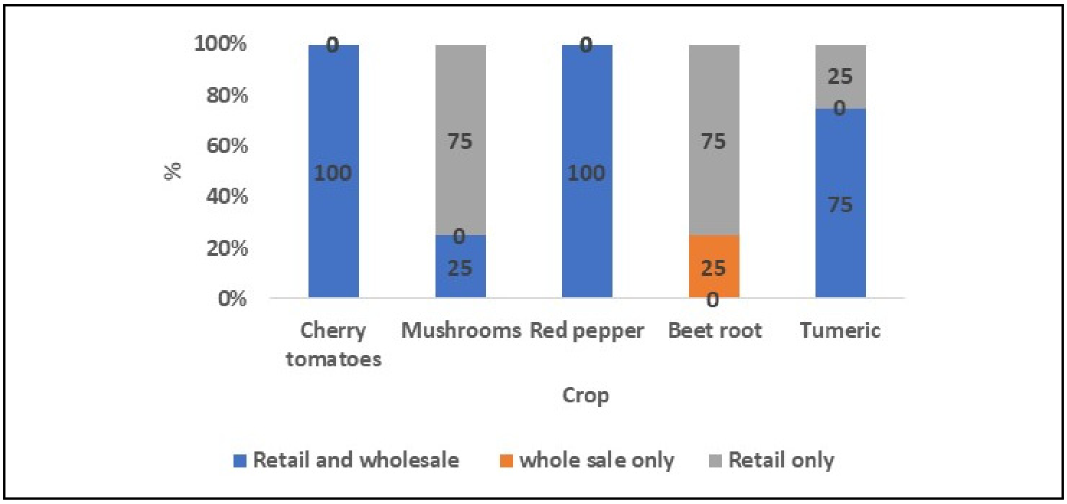
By observation, processing and marketing of functional food resources in Uganda is at infancy stage currently dominated by players in the nutrition and herbal medicine sector whose level of organization is still wanting.

The incorporation of modern technology in agricultural systems in Uganda has the potential to boost agricultural performance as modern technology and innovations give opportunities to farmers to access information on market, weather pattern, planting season and use aerial crop irrigation, moisture sensors and mobile applications for farming, this can significantly improve small holder farmers' livelihoods, hence, leading to poverty alleviation (Baumüller, 2022).

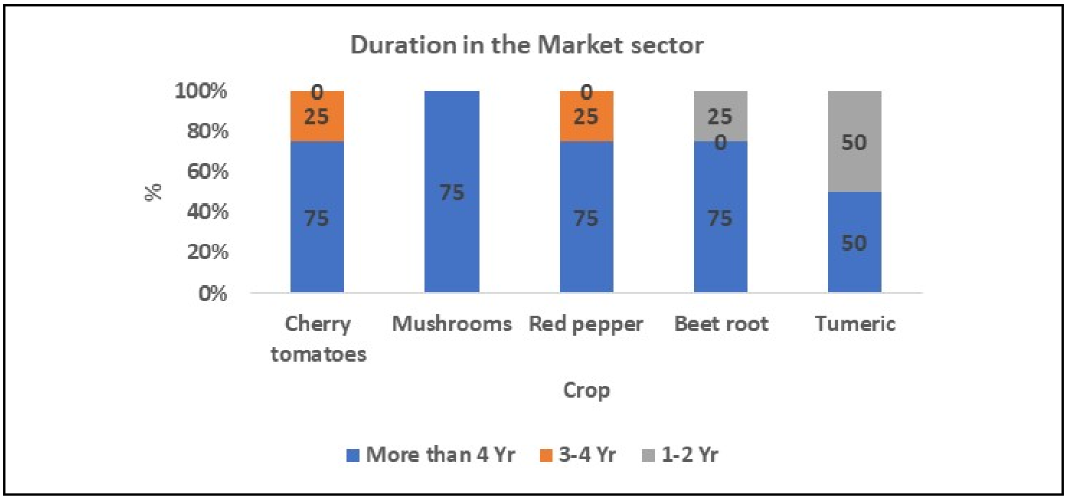
1.8. Marketing of functional plant products

Market analysis was conducted on functional plants on their values chains. For example, red pepper and cherry tomatoes were mainly sold in both retail and whole sale outlets while beet root and mushrooms in retail outlets. Most of the traders for mushroom, red pepper and cherry tomatoes had been in these businesses for more than four years.

〈Figure 2-7〉 Trading of functional crop products in Uganda



〈Figure 2-8〉 Experience of traders in functional products in Uganda



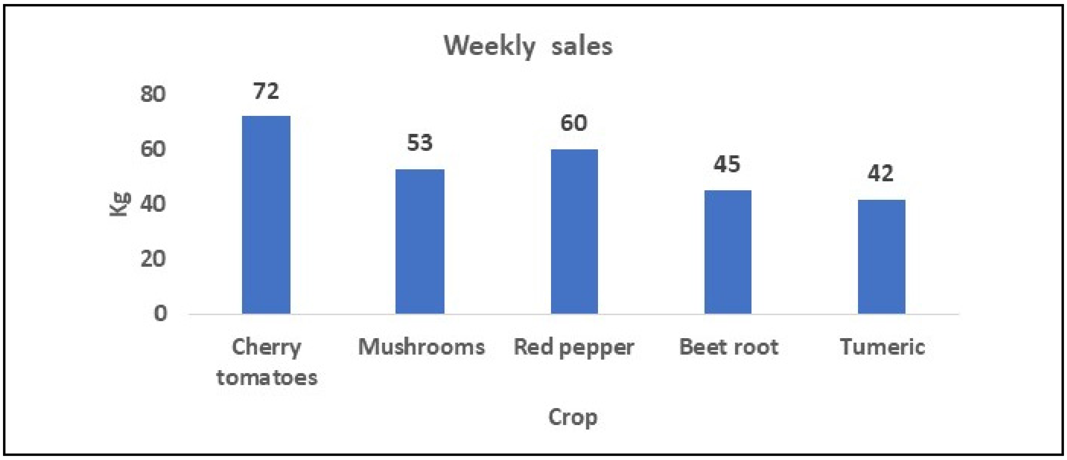
The motivation of the traders to engage in their respective businesses varied by crop. For instance, traders for cherry tomatoes were motivated by the its high market value, employment opportunity, and interest in green house production. On the other hand, mushroom traders were motivated by the increasing demand for healthy products in the market. Traders for red pepper were motivated by the increasing market demand while those for beet root by high profitability and low perishability due to its long shelf life. However, turmeric traders were motivated by the high demand for medicinal products in the market and limited losses due to its long shelf life.

〈Table 2-2〉 Factors that motivate traders of functional crops to engage in the business

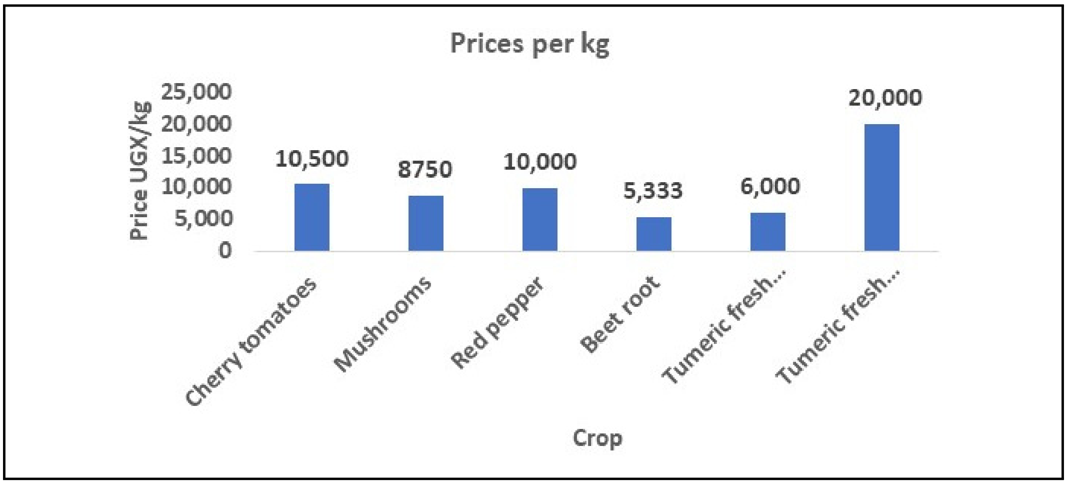
Crop	Motivation factors
Cherry tomatoes	• Limited competition • Employment opportunities • Profitability
Mushrooms	• Health benefits • Increasing market
Red pepper	• Profitability • Employment opportunities
Beet root	• Profitability • Increasing market demand • Profitability • Long shelf life • Medicinal value
Turmeric	• Profitability • Long shelf life • Medicinal value • Employment opportunities

Analysis of weekly sales of functional crops among traders was found to vary by crop. For instance, the highest sales quantity was registered among cherry tomatoes (72kg) traders while turmeric traders (42kg) had the least sale quantities per week. In contrast, the price of processed turmeric was highest at Uganda shillings 20,000 while beet root registered the lowest price at Uganda shillings.

〈Figure 2-9〉 Mean weekly sales volume of functional product /crops by trader in Kampala, Uganda



〈Figure 2-10〉 Mean prices per kg of functional crops in Kampala, Uganda



The challenges experienced by traders of functional crops was also found to vary by crop. For instance, traders of cherry tomatoes indicated perishability, limited knowledge, low supply, limited land and damage by sunlight as their challenges.

However, traders of mushroom indicated credit sales (debtors), unreliable market, variable customer needs, presence of pests on the products, variable market prices and high productions costs. However, the traders of red pepper indicated limited market and climatic factors as their major challenges. Meanwhile, beet root and turmeric traders reported limited market and high competition.

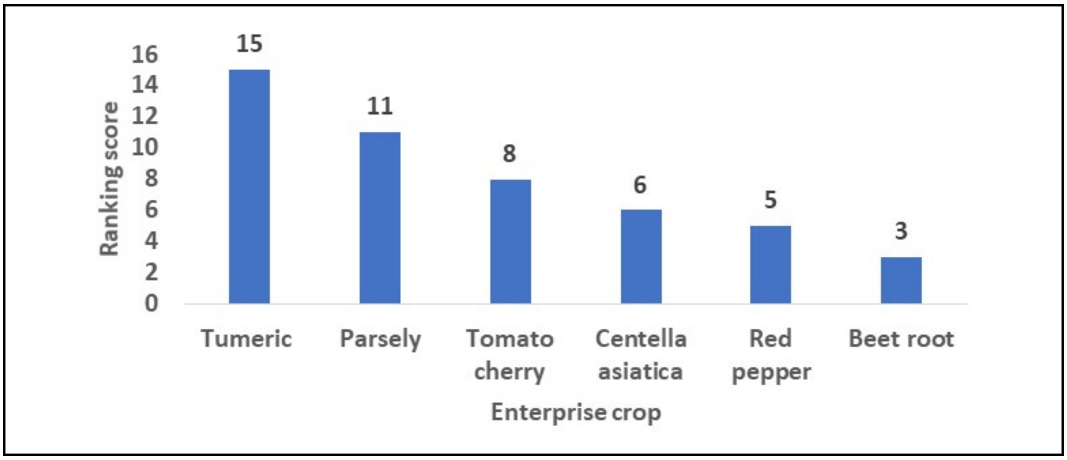
〈Table 2-3〉 Challenges faced by traders in functional crops and possible solutions

Crop	Challenge	Solutions
Cherry tomatoes	Perishability	Production by demand
	Limited skills	Consumer education on its benefits
	Low supply	Farmer sensitization on its profitability
	Sunlight	
	Limited land	
Mushroom	credit sales (debtors)	Market expansions
	Unreliable market	getting grants/loans
	variable customer needs	Market training
	Pest infestation	
	High production costs	
	Price variability	
Red pepper	Limited market	Identification of market niche
	Variable climate	Increase capital
		Identify right supplier of seeds
Beet root	Limited market	Market expansion
	High competition	Market education
Turmeric	Limited market	Strategic marketing
	Pest infestation	

1.9. Identification of an enterprise crop for smart farming

The joint research team after the production and market analyses of selected enterprise crops, decided to put them into a vote. The results of the voting had turmeric (15) with the highest score followed by parsley (11) and cherry tomatoes (8) in that order.

〈Figure 2-11〉 Enterprise crop ranking scores by the Joint Research Team



1.10. Challenges in adopting smart farming in Uganda

There are several challenges in adopting smart farming technology in Uganda, and they range from economic, infrastructural, knowledge-based to social. For instance, there is high cost of technology acquisition and high costs of technological tools and devices (accessories) like smartphones, tablets, and computers, as well as limited internet connectivity.

Limitation in accessing and using most digital extension services are attributed to low technical support for using digital device, low digital literacy level among extensionists, poor awareness on existence of digital services, high cost of internet and mobile devices, lack of ownership, control of digital services and difficulties associated with obtaining information on crop pest/disease diagnosis and management (Kansiime et al. 2022). While South Korea is establishing herself a global leader in technology development that encompasses smart farming, capitalizing on international partnership for smart farm development (Kim, Jeong, & Park, 2015), Uganda is making slow steps in prioritizing smart farm systems in their long-term plans, following the resource constraint challenge that the country is facing (Balogun et al. 2022).

Uganda faces technology infrastructure challenge which has limited the development of many sectors including the agricultural sector growth (Ogwang & Vanclay, 2021). Many Ugandan farmers, especially smallholders, have limited access to the necessary technological tools and devices (Kansiime et al. 2022). High costs of smartphones, tablets, and computers, as well as limited internet connectivity, hinder their ability to access and utilize smart farming apps and services.

The initial cost of establishing and managing smart farming system is expensive since most machinery used on the farm are expensive in terms of purchasing, transporting and maintaining (Bonabana-Wabbi, 2002). The importance of technology ICT in the agricultural sector development in Uganda is eminent and once adopted, it will enhance agricultural productivity and alleviation of poverty among farming community (Oyelami, Sofoluwe, & Ajeigbe, 2022).

Despite of the challenges, notable progress in the implementation of smart farming solutions have been registered. With limited access to reliable internet connectivity, rapid adoption of mobile phone use has been registered, this has played a significant role in disseminating agricultural information to farmers.

Digital literacy: Farmers, especially older generations, may have limited digital literacy and may struggle to effectively use digital tools and applications for smart farming. Training and capacity-building are essential to address this challenge (Kansiime et al. 2022).

Poor Infrastructure: Poor road networks to transport agricultural materials and products and limited access to electricity in rural areas makes it challenging for the farmers to use and charge electronic devices including smart phones. Internet connectivity is also unreliable further hindering the adoption of smart farming technologies (Nakawuka et al. 2018; Kansiime et al. 2022).

Technical support and repair costs: Most farmers lack access to technical support or troubleshooting assistance when they encounter issues with smart farming technology (Kansiime et al. 2022). This can lead to frustration and reduced confidence in using these tools. One of the farmers in Lira reported a big financial challenge in repairing a sprinkler and replacement of an irrigation pump when spoilt (Okuna and Mwesigwa, 2021).

Climate change: Uganda's climate variability affects the success of smart farming practices. Unpredictable weather patterns, droughts, and floods impact the effectiveness of precision agriculture and data-driven decision-making. For irrigation systems, when the dry season is long, the water level sometimes goes down and the water supply gets to be insufficient (Okuna and Mwesigwa, 2021).

Irregularity of power supply: Many rural areas in Uganda still lack electricity. Even in areas where there is electricity, the power supply by UMEME is always on and off (Okuna and Mwesigwa, 2021). This gets to negatively affect the farmers who practicing smart farming.

Other challenges faced by farmers in practicing smart farming include are, insufficient storage facilities, poor post-harvest handling practices, shortage of agricultural credit, high freight costs, and a complicated and inefficient land tenure system.

Government agencies, Non-Governmental Organizations (NGOs) and the private sector organizations have been working on initiatives to provide training, affordable technology options, and support services for farmers in support of CSA and smart farming. Furthermore, efforts to expand rural infrastructure, such as electricity and internet connectivity, are ongoing to improve the enabling environment for smart farming adoption.

2. Smart Farm Value Chain Stakeholder Survey Results

2.1. Farmers Perspective on Smart Farming Experiences

A survey conducted among farmers in Uganda on their perspectives of integrating smart farming technology (SFT) into the production of functional plants indicated that they were aware of SFT and actively engaged in smart agriculture. However, there concern was high cost of equipment, poor quality of seed, weather conditions, knowledge gap, high utility costs and pest and disease. Uganda farmer believed that the adoption of smart farming methods, such as the use of greenhouses and irrigation systems, could effectively address some of these challenges.

Additionally, farmers stressed the importance of raising awareness and education within the community and market regarding the crops cultivated under smart agriculture practices, aiming to secure favorable prices for customers.

Regarding the availability of information and training related to SFT within their community, the farmers reported that most farmers had limited access to knowledge about smart farming, resulting in a low level of awareness. When inquired about the types of support or incentives required from the government or other stakeholders to encourage them to invest in SFT, the farmers highlighted several key points.

For example, they underscored the significance of government subsidies for critical infrastructure like greenhouses, financial assistance for the implementation of smart farming technologies such as irrigation and greenhouses, the promotion of hydroponic systems, and the provision of comprehensive training and exposure to advanced farming techniques.

Lastly, the farmers shared their expectations regarding increased yields, enhanced efficiency, and greater income potential associated with the adoption of SFT for functional plant production. They believed that smart farming technology would boost crop yields by enabling precise applications of fertilizers and plant protection measures, reduce overall farming costs, offer greater reliability, and enable crop cultivation even during off-seasons without being dependent on unpredictable weather conditions. This, they anticipated, would maximize profits compared to conventional farming practices during such periods.

2.2. Machinery and Equipment supplier's experience in smart farming technology

The machinery and equipment dealers or suppliers shared that their current role in Uganda, primarily involving the provision of farming equipment and technology. While not exclusively focused on SFT, they are actively engaged in supplying equipment for agricultural purposes within the country. In the context of addressing the needs of smart farming for the production and processing of functional plant resources, they offered a range of agricultural equipment and technology solutions.

These include powered garden sprayers, irrigation pumps (water pumps), sprinklers, tractors for ploughing, and food processing machines. These tools are essential for modernizing farming practices and aligning with the principles of smart agriculture. However, they acknowledged several challenges they anticipate when introducing and selling Smart Farm Technology solutions to Ugandan farmers. Among these challenges, they highlighted.

- The potential high cost associated with acquiring and implementing such technology,
- The limited awareness and understanding of smart farming concepts among the local population, and
- The difficulties posed by software updates, especially in a context like Uganda where consistent access to updates may be challenging.

To ensure that their equipment is accessible and affordable for small-scale farmers who express an interest in adopting smart farming technologies, the dealers employ a strategic approach. Usually, they identify the most critical equipment required by small-scale farmers, and specifically target farming groups that are eager to scale up their smart farming practices, thus tailoring their offerings to meet the needs of the local agricultural community.

While they were unable to provide specific case studies or testimonials from Ugandan farmers who have adopted Smart Farm Technology, they did highlight their extensive experience in supplying agricultural machinery to various entities in Uganda. These includes individual farmers and government enterprises like MAAIF, which have reported substantial improvements in their agricultural practices as a result of using the equipment supplied by the dealers.

In terms of providing technical support and training to farmers to ensure effective utilization of SFT, the machinery dealers take a comprehensive approach. Their services encompass

- Equipment installation,
- Training sessions for farmers to learn how to operate the machinery effectively
- Regular servicing to ensure the equipment's continued functionality and efficiency.

Finally, when asked about recommendations for farmers and producers considering the adoption of smart farming tools and technologies, they emphasized several key benefits. These benefits included; the potential to reduce production costs, decrease the reliance on manual labour, and enhance overall sustainability in agricultural practices.

2.2. Food Processors of functional plant experience in smart farming technology

The agricultural processors in Uganda were interviewed to gain valuable insights into the potential application of Smart Farm Technology (SFT) in the processing of functional plants. Most of them expressed a positive outlook on how the integration of SFT could significantly impact the quality and availability of functional plant resources for food processing. Accordingly, they currently grapple with challenges related to the inconsistent supply of raw materials, both in terms of quantity and quality, throughout the year. Therefore, SFT was viewed as a promising solution to tackle these issues, offering the prospect of a more stable and dependable supply of high-quality raw materials.

Moreover, SFT was anticipated to play a crucial role in mitigating the impact of diseases and pests on raw materials, thereby reducing losses and addressing seasonal shortages. The processors also identified specific plant resources and crops that would be particularly relevant for their functional food processing businesses if supported by SFT which included; peanuts, green peas, coffee, vanilla, and various grains.

In considering the potential challenges that may arise when sourcing consistently high-quality plant materials from technologically enhanced farms, several factors were highlighted including; aggregation of resources, post-harvest handling practices, concerns related to misinformation, and the necessity for effective post-harvest handling methods.

However, addressing these challenges is deemed essential to ensure a seamless supply chain for high-quality plant resources. SFT is expected to drive innovation in the development of new and novel functional food products. It holds the promise of enabling controlled production of plant varieties with desirable characteristics in the required quantities and quality consistently throughout the year. Furthermore, SFT may facilitate the cultivation of non-indigenous crops by accommodating varying climatic needs, opening up opportunities for the creation of new products that were previously constrained by the availability of raw materials.

The processors emphasized the importance of regulatory and quality assurance aspects when sourcing plant resources from technologically enhanced farms for food processing. Compliance with regulations, thorough inspection, benchmarking, automation, quality control measures, risk management practices, and rigorous testing for factors like aflatoxins were all underscored as critical considerations. These measures are essential to eliminate potential hazards and ensure that the products derived from these resources are safe for consumption.

To maintain the nutritional and functional qualities of plant resources, processors highlighted the significance of close collaboration with farmers and technology providers. Such collaboration should commence in the planning phases, allowing processors to articulate their requirements and the desirable traits expected by end consumers. This collaborative effort should also encompass the implementation of good agricultural and veterinary practices on the farm, the judicious use of authorized chemical inputs, appropriate harvesting techniques, effective on-farm storage, and handling practices. Furthermore, the development of sustainable and technologically reliable methods for transporting plant resources to processors without compromising quality was deemed crucial. In conclusion, processors in Uganda hold an optimistic perspective regarding the potential of Smart Farm Technology to elevate the quality, availability, and innovation of functional plant resources for food processing. However, they acknowledge the necessity for collaboration and the careful consideration of regulatory and quality assurance aspects to ensure the successful integration of SFT into the supply chain, ultimately benefiting both the industry and consumers.

3. Agricultural Policies Review of Uganda

MAAIF's of Uganda vision is to establish a competitive and profitable agriculture sector in the country. The mission is to transform subsistence farming into commercial agriculture. The Crop Production Department's mandate is being to promote, guide, and support sustainable, market-oriented crop production, value addition, increased household income, and food and nutrition security.

The Constitution of the Republic of Uganda, 1995 recognizes citizens' fundamental rights to food and nutrition security.

3.1. Uganda Vision 2040

Uganda Vision 2040 (UV 2040) defines the development pathway and strategies that will transform Uganda from a predominantly peasant and low-income country to a competitive upper middle-income country. It is a long-term development framework designed to transform Uganda into a middle-income country by the year 2040. The Uganda Vision 2040 envisions a transformation of Ugandan society from peasantry to modern prosperity commercial agriculture. This shift involves adopting modern farming practices, such as the use of technology, improved crop and livestock management, and efficient resource utilization. Smart farming practices are essential for increasing agricultural productivity and income.

The UV 2040 recognizes agribusiness as a key driver of economic growth. Smart farming encompasses agribusiness activities that utilize technology for precision agriculture, data-driven decision-making, and value addition. Uganda Vision 2040 emphasizes technology and innovation in various sectors, including agriculture and this is precisely what Smart farming is all about as it adopts various and UpToDate technology, including the use of ICT tools, data analytics, and precision farming techniques to optimize agricultural processes.

The UV 2040 as well prioritizes value addition to agricultural products. Smart farm production and processing of functional plant resources fit well into this policy framework that not only focuses on production but also on the efficient processing and marketing of agricultural products. This aspect of value addition increases income of farmers and ensures that functional plants are processed and utilized effectively. The UV 2040 acknowledges the need for skills development and capacity building in the agricultural sector. Training and education programs are essential for equipping farmers and agricultural stakeholders with the knowledge and skills required for smart farming practices. Smart farming practices promote sustainability by reducing resource waste, minimizing environmental impacts, and ensuring the efficient use of resources which aspects of environmental sustainability are well captured in UV 2040. Additionally, UV 2040 encourages the diversification of agriculture to include high-value crops and non-traditional agricultural products. This diversification aligns with smart farming practices that promote the cultivation of functional plants among others.

3.2. Uganda's National Development Plan III (NDP III) (FY 2020/21–2024/25)

The NDP III is the third in a series of six five-year plans aimed at achieving the Uganda Vision 2040. It is a key policy document that outlines the Uganda government's priorities and strategies for economic and social development over the five-year period 2020/21 to 2024/25. NDP III emphasizes the modernization of agriculture as a key driver of economic growth. The plan encourages the adoption of advanced farming techniques to improve agricultural productivity. Smart farming practices encompass the use of technology, precision agriculture, and data-driven decision-making which are integral to the modernization of agriculture.

NDP III recognizes the importance of water resources for agriculture. It includes provisions for expanding irrigation schemes and improving water management practices, which are essential for the sustainable cultivation of functional plants. NDP III underscores the importance of research and innovation in agriculture. It supports the development and dissemination of new agricultural technologies and practices. Research and innovation are key drivers of smart farming. Furthermore, the NDP III framework emphasizes environmental sustainability, agricultural diversification, support of small holder farmers and recognizes the role of digital technology and ICT in enhancing agriculture.

3.3. National Agricultural Policy (NAP)

The Agricultural sector of Uganda is greatly influenced by the National Agriculture Policy (NAP) which was approved in 2013 by the Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) to achieve food and nutrition security and improve household incomes through coordinated sustainable agricultural productivity and value addition, better employment opportunities and promoting domestic and international trade (Mugagga et al. 2018).

NAP also partly seeks to develop a private sector led agriculture sector in Uganda. The NAP was developed to harmonize the different ideas and approaches to national agricultural development. The vision of the policy is “a competitive, profitable and sustainable agricultural sector”, while the mission of the policy is to: “transform subsistence farming to sustainable commercial agriculture.”

The overall objective of the policy is “to achieve food and nutrition security and improve household incomes through coordinated interventions that focus on enhancing sustainable agricultural productivity and value addition; providing employment opportunities, and promoting domestic and international trade”. The

NAP promotes sustainable and modern farming practices, including the use of technology in agriculture. It emphasizes value addition and agro-processing, which are critical aspects of processing functional plants.

3.4. National Irrigation Policy (NIP)

The NIP of Uganda aims to ensure sustainable availability of water for irrigation and its efficient use for enhanced crop production, productivity and profitability that will contribute to food security and wealth creation (Gabiri et al. 2022). The irrigation policy is to ensure improved and expanded irrigation infrastructure and practices contributing to poverty alleviation and economic growth in Uganda as a result of farmer managed, small scale schemes and best practice service delivery and an enabling investment environment for irrigated crop production, value addition and/or service provision. The irrigation policy focuses on smallholder farmers practicing subsistence farming and emerging farmers moving from subsistence to commercial farming ; and commercial farmers who grow cash crops to increase their agricultural production and productivity. Irrigation contributes to sustainable food production and food security, poverty alleviation, and increases the economic growth with the schemes focusing on increased yields of high value crops, value additions and livelihood differentiation accruing to increased trade goods and market activity (Mugagga et al. 2018).

3.5. National Environment Management Policy 1995

The National Environment Management Policy seeks to promote development that enhances environmental quality and resource productivity on a long-term basis to meet the needs of the present generations, without compromising the ability of future generations to meet their own needs. This is especially important because land degradation is a major threat to agricultural productivity in Uganda. Agricultural practices are already having an impact on Uganda's natural ecosystems and this is undermining the delivery of ecosystem services. Moreover, ecosystem services are crucial for agricultural production and the encroachment of cultivation into natural ecosystems is itself severely undermining the sustainability of agricultural growth.

NEMP establishes the overarching framework for environmental conservation, management, and sustainable development in the Uganda. While the NEMP primarily focuses on environmental issues, it plays a significant role in promoting smart farming practices that align with sustainable and environmentally responsible agricultural production. The NEMP encourages sustainable land use practices, which are essential for smart farming. Smart farming involves optimizing land use through precision agriculture, crop rotation, and diversified cultivation, all of which contribute to soil health and long-term sustainability. Smart farming relies on efficient water management. The NEMP emphasizes the protection and sustainable use of water resources, which are crucial for irrigation, livestock, and crop production in smart farming systems. Smart farming often integrates climate-smart agricultural practices to mitigate the effects of climate change.

3.6. The National Agricultural Advisory Services Act

The National Agricultural Advisory Services Organization (NAADS) is a semi-autonomous public agency within the Ministry of Agriculture Animal Industry and Fisheries (MAAIF), responsible for public agricultural advisory/extension services. The National Agricultural Advisory Services (NAADS) Programme was created in

2001 by an Act of Parliament to specifically address constraints of lack of access to agricultural information, knowledge, and improved technology among rural poor farmers in the country (Mugagga et al. 2018). The NAADS act envisions a decentralized farmer owned/controlled agricultural advisory service system with increasing participation of the private sector. Its mission is to increase farmers' access to information, knowledge, and technology for profitable agricultural production. With Smart farming and processing of functional plant materials oriented towards technological application for increased quality and quantity of agricultural products including functional foods blends well with the NAADS act.

3.7. Uganda Nutrition action Plan II (2020/2021-2024/2025)

The Goal of this Policy is "Improved nutrition status among children under five years, school-age children, adolescents, pregnant and lactating women and other vulnerable groups by 2025". Some of the key strategies include: Promote optimal micro-nutrient intake among children, adolescent girls and women of reproductive age in stable and emergency situations; Increase coverage of the management of acute malnutrition in stable and emergency situations; Integrate nutrition services in the prevention, control and management of infectious diseases and epidemics. Integrate nutrition services in the prevention, control and management of diet-related non-communicable diseases; Increase the production of diverse, safe and nutrient-dense food at the household level from plant, fisheries and animal sources; Increase access to diverse, safe and nutrient-dense food from plant, fisheries and animal Sources; Increase the utilization of diverse, safe and nutrient-dense food from plant, fisheries and animal sources.

3.8. The Uganda Green Growth Development Strategy (UGGDS 2017/18 –2029/30)

This policy aims to ensure that the goals of the Uganda Vision 2040 and the NDPII 2015/16-2019/20 is attained in a sustainable manner. Sustainable agriculture production through upgrading the value chain of strategic commodities and enterprises with a focus on irrigation and integrated soil fertility management is one of the 5 focus areas of this policy.

3.9. Food and Nutrition policy (2003)

It is intended to ensure that the entire food chain, from production to consumption, is efficiently managed within the overall development strategy, through building capacities at all levels for adequate action to improve household food security. However, the policy contains limited discussion on the relationship between food and nutrition security and climate change and hence needs to be reviewed. Food and Nutrition Security Policy plays a role in reducing post-harvest losses and addressing food insecurity issues.

Other policies related to the production of functional plant resources include: National Science Technology and Innovation Policy which goal is to strengthen national capability to generate, transfer, and apply scientific knowledge, skills and technologies that ensure sustainable utilization of natural resources for the realization of Uganda's development objectives; and National Water Policy which provides a framework to support management of Uganda's water resources in an integrated and sustainable manner.

Current policies and regulations on production and processing of functional plant resources and related sectoral policy instrument objectives resonate well with smart farming and Climate-Smart Agriculture framework to address food security in a sustainable manner resulting in adaptation to and mitigation of climate change. The Agriculture Sector Strategic Plan clearly positions smart farming as an important mechanism for improving the sector's performance and sustainability.

The Ugandan government has committed to developing frameworks that will improve inter-ministerial and local government coordination; enhance partnerships with private sector and civil society organizations; and strengthen coordination with development partners that are embedded within the production and processing lines of functional plant resources. Smart farming production and processing of functional plants employs modern technology including artificial intelligence (AI) and internet of things (IoT) to improve quality and quantity of farm products. Additionally, the processing of the functional plant materials greatly adds value to these products greatly boosting economies of not only the farmers but the country. Thus, the Uganda government policy frameworks and regulations support this approach.

These policy frameworks although support improvement in agricultural production and boost to the economy, the policies don't evidently bring out a clear roadmap for developing smart farming system. In Uganda, separate smart farming interventions implemented by competing private sector and others promoted by Non-Governmental Organizations and Government institutions have resulted into high-tech solutions that are advancing the smart farm concept in Uganda (Vargas et al. 2019).

The strategic objective of the Agro-industrialization (AGI) Program under the NDP3 (20/21-24/25) is highlighted as a key driver of MAAIF's policies. The AGI program aims to increase household incomes through the commercialization and competitiveness of agricultural production and processing. This program is supposed to Increasing Agricultural Production and Productivity, Improving post-harvest handling and storage of agricultural products, Increasing Agro-Processing and Value addition, market access and competitiveness of agricultural products in both domestic and international markets. It also tries to increase mobilization, access, and utilization of agricultural finance strengthening the agriculture sector's institutional capacities for Agro-Industrialization.

The Parish Development Model (PDM) recently develop government, specifically in Pillar 1, focuses on increasing production and productivity across the value chain to support food security and income improvement at the household level. This includes supporting horticultural crops like fruits and vegetables. The MAAIF's role in PDM is organizing and coordinating farmers at the parish level, linking them to industrial hubs, and advising on access to local and international markets. Furthermore, MAAIF is involved in capacity building, database management, support for community-level facilities, and input regulation.

To align with AGI and PDM objectives, MAAIF adopted the Agricultural Value Chain Development Strategy (AVCDS) to commercialize agriculture. This approach ensures market led production and profitability to enhance household incomes. Core areas directed by the President to focus on within AGI: included

- Promoting seed and stocking material production, multiplication, certification, and distribution.
- Pest and disease control.
- Mechanization and irrigation.
- Farmer mobilization and education.
- Partnerships with commercial farmers for strategic commodities.
- Special intervention for the fisheries sub-sector and aquaculture development.

The suggested programs in the promotion of functional crops is subsidizing processed functional resources for the elderly, offering capital to SMEs for advanced processing units, fund for research on functional resources and auxiliary technologies supporting their processing. The government of Uganda has been promoting modern farming practices, technological innovations, and value addition in the agricultural sector to improve productivity and income for farmers.

3.10. Policy issues in smart farming

The joint research team interviewed policy makers of Uganda to gain insights into their perspectives on the application of Smart Farm Technology (SFT) in the processing of functional plants. Accordingly, policy makers are responsible for promoting, guiding, and supporting sustainable market-oriented crop production and value addition, with the aim of increasing household income and ensuring food and nutrition security.

It was clear from the discussion with policy makers that there was a basic understanding of SFT among them. The policy makers indicated use of smart technologies such as data apps and internet-connected equipment for automation of farming, but acknowledged that SFT is still relatively new in Uganda. However, there were initiatives and projects with objectives aligned to SFT adoption.

Introduction of SFT would result in the emergence of more programs and initiatives over time to promote its use. Consequently, SFT holds significant potential to contribute substantially to Uganda's agricultural development by increasing production and productivity, enhancing household incomes, improving food security, and ultimately raising GDP.

Additionally, policy makers believed that SFT can facilitate better access, utilization, and consumption of functional plant resources. Moreover, policy makes expressed confidence in the current policies and regulations, considering them highly effective in promoting the adoption of SFT. For instance, PDM can be as a means to directly introduce SFT to farmers.

In order to encourage farmers to adopt SFT, they have already put forward several policy initiatives and incentives. These include rural 19 electrification, increased water availability for production, improved storage facilities, value addition technologies, and enhanced market infrastructure, such as roads, internet access, and smartphones.

However, it was also acknowledged various barriers that hinder farmers from adopting SFT. These include limited access to the internet and smartphones, expensive and unreliable electricity supply in rural areas, the need for training and knowledge, poor infrastructure, inadequate irrigation, marketing challenges, and insufficient availability of high-quality seeds and planting materials.

The policy makers proposed the use of the PDM to categorize farmers into commodity clusters and introduce SFT to them. By organizing farmers into groups, they believe that the government can provide tailored support in terms of SFT based on their specific needs. In their view, there are no regulatory challenges currently hindering the widespread adoption of SFT. However, they have emphasized the importance of any regulatory changes aligning with the MAAIF policy interventions and directions.

Policy makers also underscored the significance of testing new varieties and planting materials before promotion. The proposed strategies were to raise awareness and build capacity encompass supporting farmer groups and associations to invest in SFT, training stakeholders, including ministry and local government staff, and retooling public extension workers and model farmers to become experts in SFT. The emphasizes were to build collaborations between policy makers, researchers and farmers. But researchers were recommended to focus on developing modern farming technologies and seeds, while policy makers concentrate on creating enabling policies for farmers to adopt SFT and benefit from these technologies.

Generally, an awareness of the potential benefits of SFT and expressed openness to policy initiatives and incentives aimed at promoting its integration into the agriculture sector were identified as important, especially in aligning interventions with existing policies and addressing the specific challenges faced by farmers to ensure the successful adoption and equitable distribution of benefits.

3.11. Policy Implementation and Recommendation

Policy recommendations related to the adoption of smart farming technology in the production and processing of functional plant resources include;

- Allocate funds for research and development focused on smart farming technologies.
- Private sector to collaborate with research institutions to develop and adapt smart technology solutions specific to functional crops.
- Strengthen policy implementation on ensuring availability of high-quality inputs such as certified seeds, fertilizers, and advanced agrochemicals that are compatible with smart farming practices.
- Develop and promote policies that encourage climate-resilient agricultural practices, including the use of smart irrigation systems, weather monitoring, and drought-resistant crop varieties.
- Create policies to facilitate the adoption of mechanization in agriculture, including incentives for farmers to invest in modern farming equipment and machinery that can improve efficiency. Invest in rural infrastructure, including roads and storage facilities, to ensure that functional foods can be transported efficiently and stored properly, reducing post harvest losses.
- Establish programs for training and capacity building among farmers, extension workers, and agricultural professionals to ensure they are proficient in using smart farming technologies effectively.
- Support initiatives that enhance market access for functional crops through technology-driven marketing platforms, both domestically and internationally.
- Promote policies that encourage the sharing of agricultural data and information through digital platforms, enabling farmers to make informed decisions.

3 Case Study on Medicinal Crop Smart Farms in Korea

1. Joint Research Team Experience of South Korea Smart Farming Technologies

The Joint Research Team shared the South Korea experience of smart farming technology. These included; integration of information, data software tools, and technology to enhance agricultural production. This approach results in the generation of a substantial amount of data and information, with a gradual introduction of automation. There were observed differences between South Korea and Uganda in terms of their smart farming approaches.

While crops grown in S. Korea under SFT had an established plan, roadmap, policies, budget, and funding with a strong focus on intensive Research and Development (R&D) and international partnerships, Uganda did not have it. Therefore, S. Korea can participate in the exportation of knowledge, technologies, and products to other countries like Uganda.

The invitational training of Uganda team to the Republic of Korea focused on smart farming technologies and related policies. There were several field activities in S. Korea that included;

- Gyeongsang National University Smart Farm Research Center
- Gyeongsang National University Department of Life Resources Science and Functional Materials Production Facility
- Dream Farm (Compact Smart Farm Facility Tour) Related Organizations and tour of company demonstration facilities
- Jeonnam Goheung Smart Farm Innovation Valley
- Jeonnam Forest Resources Research Institute research facility tour
- Korea Institute of Oriental Medicine Headquarters
- Introduction to UST international cooperation and human resources training projects
- Dongshin University's research facilities and medicinal plant greenhouse facilities
- Korea University of Agriculture and Fisheries smart farm facility
- Rural Development Administration (RDA) Agricultural Science Museum and the Advanced Digital Greenhouse at the Institute of Horticultural and Herbal Science

1.1. Gyeongsang National University

This Smart Farm Research Center takes an interdisciplinary approach in biosystems engineering, integrating engineering, science, and design with applied biological, environmental, and agricultural sciences including; Animal smart farming, ICT smart farming, mechanical smart farming, and plant smart farming; Remote sensing and GIS technologies; Non-invasive detection and quantification of gray mold disease on strawberry plants; Aerated poultry compost; and greenhouse microclimate control development.

〈Figure 3-1〉 Strawberry smart farm facility at Gyeongsang National University Smart Farm Research Center

The focus of this research facility is on optimal conditions for the growth of target plants, the transition of plants from laboratory settings to greenhouse systems, and the management of plant pathogens in controlled environments. The major smart farm essentials include;

- Lighting requirements i.e. light intensity, duration, and spectrum, to ensure the optimal growth of the plants
- Nutrient needs i.e. type and concentration of fertilizers provided to plants
- Temperature conditions optimization to mimic the natural habitat
- Humidity level control levels
- Greenhouse designed to minimize the entry of external contaminants, reducing the risk of pathogen introduction

1.2. Dream Farm (Compact Smart Farm Facility)

Dream farm provides cutting-edge smart farming technology in terms of fabricating green house for farmers to cultivate crops while offering precise control over environmental conditions, such as lighting, temperature, and humidity. The company is driven by decreases in food supply and aging population of South Korea, and the technology allows remote monitoring of crops and environmental conditions & use of solar panel for energy in the green houses. In this green house, the crop enterprises are isolated from the external environment. There greenhouses were targeted for plants including wakish, lettuce, strawberry, mushroom and ginseng. It was reported that an initial investment for such a greenhouse was about USD 50,000 in S. Korea.

1.3. Jeonnam Goheung Smart Farm Innovation Valley

The joint research team had experience at Jeonnam Goheung Smart Farm Innovation Valley that was started in 2020 by the Government of S. Korea at an estimated cost of about USD 89 million. The motivation to set up such a facility was the aging farmer population of S. Korea. This facility operates with a set of clear objectives, fostering talent development, technological advancement, and sustainability in agriculture and crops of focus were strawberries, tomatoes, melons, late-maturing citrus, and various subtropical crops. The centre is housing a big data center that plays a crucial role, and provides rental smart farms for local farmers and residents. Currently the centre trains 52 students per year and so far three cohorts had been admitted totaling to about 200 students.

1.4. Jeonnam Forest Resources Research Institute

The joint research team has an opportunity to visit Jeonnam Forest Resources Research Institute research facility that provided a unique opportunity to witness the construction process of several greenhouses, that considered the environmental conditions of the region.

1.5. Korea Institute of Oriental Medicine

KIOM was another experience where the team was provided with a comprehensive overview of the institution's major research activities in the field of oriental medicine of S. Korea. The institute is focusing to bridges the gap between traditional oriental medicine concepts and modern scientific knowledge through standardization of the diagnosis and treatment processes within oriental medicine. The institute is also reported to be actively engaged in international cooperation efforts to promote traditional medicine.

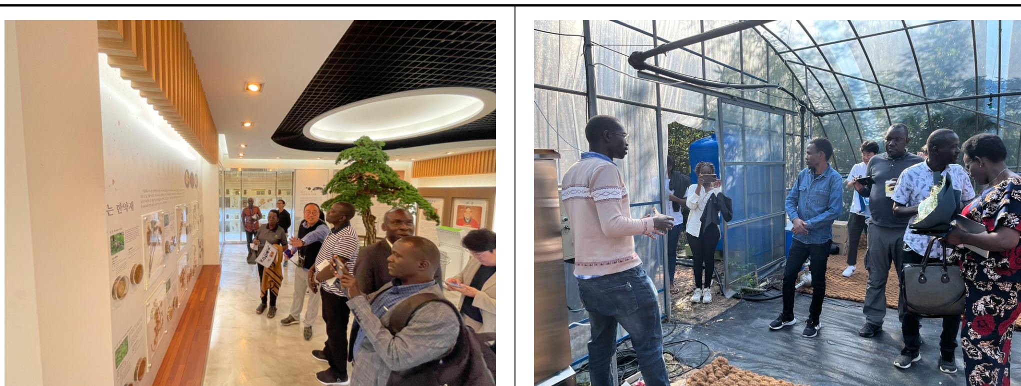
1.6. University of Science and Technology (UST)

The Joint research team had an experience at UST co-founded by 32 research institutes of S.Korea. UST is different from the traditional universities globally as it provides valuable insights into the institution's structure, programs, and objectives, and interdisciplinary research hubs and education. Moreover, UST plays a crucial role in sourcing technology and promoting industrial technology development in South Korea. The university welcomes international students to join and currently has about 15,000 students and 1300 are professors.

1.7. Dongshin University

The joint research team also visited Dongshin University's research facilities and medicinal plant greenhouse facilities that provided an insight into the establishment and functions of the greenhouse. Although the facility was under construction, it is an essential asset for the cultivation of medicinal plants and micro propagation processes. It was indicated the greenhouse under construction was majorly for stabilizing plants for the growing environment.

〈Figure 3-2〉 Field trip to KIOM and Dongshin University



1.8. Korea University of Agriculture and Fisheries

The joint research team had an experience at the Korea university of Agriculture and fisheries. This research facility provided an valuable insights into the cultivation of mushrooms within a smart farm system. The team was explained the successful oyster mushroom cultivation process within the smart farm system taking into key conditions including lighting, carbon dioxide, and sources of carbon and nitrogen. For instance, the nitrogen source in this research facility were rice bran, soy bean while the carbon sources included; sow dust, cotton seed and corn cobs. Water (50~70%) was identified as essential in mushroom production. About 1kg of substrate produces was reported to product about 350g of mushrooms in the first harvest, 200g in 2nd harvest and 100g in the 3rd harvest.

1.9. Rural Development Administration (RDA)

The experience of the joint research team at RDA was essential as it gave an insight into continued generation of advanced agricultural technologies that can converge with ICT-BT, as well as actively developing field-based technologies with practical applications for the benefit of farmers. The organization is championing the 6th industrialization, development of seeds and new materials, mechanization of upland field cropping, and technological support for export market development. It also provided an insight into advanced smart farming technologies with an optimum height of the green house including use of a robot instead of the person in crop spraying.

The crops under cultivation in this smart farm included; strawberry, tomatoes and yellow melon. Currently, the production of strawberry was throughout the year using artificial climatic conditions. Artificial intelligence /big data was being utilized in detection of pests, prediction of maturity and harvest, rate of fruit ripening based on colour, size and height/light and optimization of maturity.

4 Conclusion

1. Conclusions and Recommendation

Current policies and regulations on production and processing of functional plant resources and related sectoral policy instrument objectives resonate well with smart farming and Climate-Smart Agriculture framework to address food security in a sustainable manner resulting in adaptation to and mitigation of climate change. These policy frameworks although support improvement in agricultural production and boost to the economy, the policies don't evidently bring out a clear roadmap for developing smart farming system.

In Uganda, separate smart farming interventions implemented by competing private sector and others promoted by Non-Governmental Organizations and Government institutions have resulted into high-tech solutions that are advancing the smart farm concept in Uganda. An ideal greenhouse for Uganda should have the gutter level at least 4 meters, ridge height at 6 meters and the top vent of at least 70cm to 1 meter. The top vent serves as a temperature regulator, ensuring a conducive environment for plant growth. These specifications are crucial for creating a controlled microclimate that enhances crop yield and quality.

2. Proposal for Official Development Assistance(ODA) Project

2.1. Project Description, Goals and Objectives

Uganda is a country already experiencing major impacts of climate change such as changing weather patterns, frequent and severe dry spell, reduced water levels, and increased occurrence of extreme weather events like floods, drought, and increased incidences of pests and diseases. According to Soumitra Dutta & Wunsch-Vincent, (2022), Uganda is ranked 154 out of 165 nations on the Notre Dame Global Adaptation (ND-GAIN) Index 1, which means the country is highly vulnerable to climate change. Consequently, impact of climate change has led to reduced agricultural outcomes (McKinney & Wright, 2021). Nevertheless, agricultural development through technology improvement and farm digitalization is gradually taking shape in the transformation of farming systems in Uganda. The Uganda NPA is advocating for a digitalization agenda which will benefit the development of smart farming systems as a way of contributing to achieving Uganda Vision 2040.

Currently, the government of Uganda, through the MAAIF is partnering with different countries to promote the use of modern agricultural technologies as is greatly affected by unfavorable climatic changes (Opok and Mwesigwa, 2021). Although FANRPAN (2017) indicates that climate smart farmers can get thrice their usual yields (Opok and Mwesigwa, 2021), agricultural production practices in Uganda are unfortunately still largely traditional (Dayoub et al., 2021). Many farmers use the conventional methods of farming which results in low yields and poor-quality products that are unfit for the market both locally and internationally (Dayoub et al. 2021).

Smart farming technology that involves the use of advanced technologies to optimize various aspects of agriculture, including crop production, livestock management, and resource utilization is being advocated. This technology primarily depends on the use of artificial intelligence (AI) and internet of things (IoT) in cyber-physical farm management, use of GPS, GIS and UAVs, automation and robotics, data analytics and AI and smart irrigation. It is presumed that smart farming can address food security challenges in Uganda. These holds promise to revolutionize sustainable food production to improve efficiency, sustainability, and market competitiveness of Uganda functional plant resources.

Functional plants play an increasingly important role in food and health. For instance, Turmeric (Curcuma longa), Parsley (Petroselinum crispum), Crotalaria spp, Hibiscus and Cherry tomatoes (Solanum lycopersicum var. cerasiforme) have for long been used in Uganda for both nutritional and medicinal benefits. Turmeric is rich in bioactive compounds like curcuminoids, curcumin, demethoxycurcumin, and bisdemethoxycurcumin with health-promoting properties including; antioxidant, anti-inflammatory, anti-asthma, anti-diabetic, anti-virus, anti-arthritis, antimicrobial, anti-metabolic syndrome, anti-cancer properties. Parley is rich in flavonoid and other poly phenolic compounds, containing furanocoumarin, carotenoids, polyacetylenes, and its leaves are a source of vitamins and minerals. The most important parsley compounds offer diuretic, antiurolithiasis, hypouricemic, hypolipidemic, hypoglycemic, hypo tensive, antioxidant, anti-inflammatory and anti platelet effect. Tomato (Solanum lycopersicum L) is one of the most widely consumed fruits in the world, and is rich carotenoid lycopene (Schierle et al. 1997; Holloway et al. 2000; Livny et al. 2002) that is essential in human nutrition (Khachik et al. 2002) as it possesses anticancer properties (Fraser and Bramley, 2004) and reduces the risk of chronic diseases such as cardiovascular diseases and cancer (Niranjana et al. 2015). Hibiscus (Hibiscus sabdariffa Linn) widely distributed and cultivated worldwide is a rich source of pigments for cosmetics and food applications, and is used to treat many ailments including diarrhea, hypertension, bronchitis and cough, Ceylon mouth among others. Hibiscus can be processed as beverages, syrup, jelly, wine, pudding, cakes among others. Crotalaria is a rich source of flavonoid, anthraquinone, phenols, polyphenols, steroids and alkaloids (Edgar et al, 1992) and it has been used in traditional medicine to treat cancer, eczema, gout, hydrophobia, pain, wounds and cuts, infection, renal pain, stomach disorders, rheumatism, and joint pain, and edema. The root extract is used to alleviate chronic kidney pain and treat typhoid fever.

However, use of Smart farming technologies in Turmeric, Parsley, and Cherry tomatoes, Hibiscus and Crotalaria production have not been explored in Uganda, despite its ability to improve efficiency, sustainability, and market competitiveness of agriculture products. Turmeric, Parsley, and Cherry tomatoes, Hibiscus and Crotalaria.

2.2. Project Justification

Like many other sub-Saharan nations, Uganda has long struggled with severe chronic poverty and issues related to health and nutrition. However, functional plants play an increasingly important role in nutrition and health due to their abilities of prevent and treat diseases. These Parsley, Cherry tomatoes, Hibiscus, Crotalaria and turmeric. For instance, Crotalaria is reported to possess antitumor, antineoplastic, antioxidant, anti-inflammatory, and neuroprotective properties. Turmeric (Curcuma longa) has also been utilized for thousands of years for a variety of medicinal applications including anti-arthritis, antioxidant, liver support, improved brain function, protection against neurodegenerative illnesses like Alzheimer's, immunomodulatory and skin care. Hibiscus known to be rich in Beta carotene, vitamin C, protein and total sugar has been reported to have possesses nutritional and medicinal properties. Seeds, leaves, fruits, and roots of hibiscus are used in various foods as well as in herbal medicine for treating cardiovascular disorders, helminthics, cancer, as an anti-oxidant and in obesity management. Cherry tomatoes rich in bioactive lycopene and α-tomatine possess anticancer and antioxidant activity. Parsley that belongs to the carrot family (Apiaceae) has become an essential ingredient in cooking, and possess antidiabetic, antioxidant, anti-inflammatory, analgesic and spasmolytic activity.

Despite these medicinal applications, several challenges still do exist in the production and processing of Parsley, Cherry tomatoes, Hibiscus, Crotalaria and turmeric functional plants. These challenges include; seasonality of the crops, labor intensive and expensive methods of production, low quality and safety, perishability and increased use of pesticides due to increased pests and diseases caused by effects of climate change. Smart farming systems can be a promising solution to address the problem of low income and poor health in Uganda by producing high-quality, nutrient-rich functional products. This project is to utilize smart farming systems for production of Parsley, Cherry tomatoes, Hibiscus, Crotalaria and turmeric in Uganda for sustainable farming practices that produce high-quality, nutrient-rich foods while minimizing the environmental impact of agriculture and improving the livelihoods of farmers and the health of the population.

2.3. Project Problem Statement

Smart farming of functional plants like Hibiscus, Parsley, Turmeric, Cherry tomatoes and Crotalaria can provide solutions to address the problem of low income, nutrition and poor health, and contribute to export earning, farmers face several challenges including; low productivity, perishability, low quality of products, poor access to markets, increased use of pesticides and limited access to finance and technology. While Smart farming can help farmers overcome these challenges by providing remote monitoring and control systems that optimize water usage, fertilizer delivery and reduce pesticide and energy consumption, increase their productivity, quality and reduce their input costs, leading to higher incomes, there is lack of proper infrastructure and technical know-how skills to produce high-quality, nutrient-rich foods that can improve the health of the population.

The bioactive compounds including vitamins, minerals, and antioxidants in Hibiscus, Parsley, Turmeric, Cherry tomatoes and Crotalaria in the current opening farming system vary due to climatic factors, making them not effective in health and nutrition provision. Moreover, the climatic variability increases pest and disease on these functional plants causing farmers to increase pesticide use in order to improve productivity, which is disastrous to their health and health of consumers. Crops with high pesticide concentration fetch low market prices as it is rejected from international market. Even pest infested crops without pesticides also have low productivity and fetch low market prices which intern make farmers get low income at house hold level.

2.4. Project proposed solution

The incorporation of modern technology in agricultural systems in Uganda like smart framing has the potential to boost agricultural performance as modern technology and innovations give opportunities to farmers to access information on market, address challenges of weather variability and have crops throughout the year. Smart farming can allow use of aerial crop irrigation, moisture monitoring and mobile applications for farming. This can significantly improve small holder farmers' livelihoods, hence, leading to poverty alleviation (Baumüller, 2022). Modern systems for production and processing of safe, high value, and high quality Turmeric, Parsley and Cherry tomatoes functional plant can increase income among the farmers involved in production and increase their market potential.

2.5. Project Overview

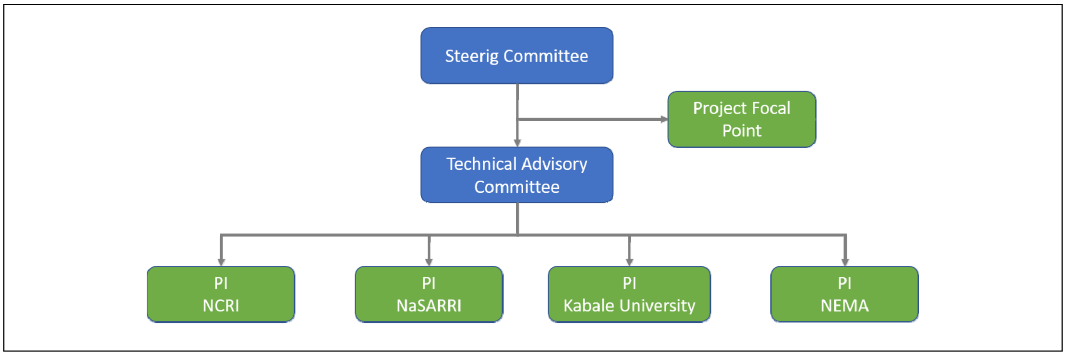
2.5.1. Project Goal

- The project goal is to establish a paradigm of integrated and sustainable production and processing of turmeric, parsley, Cherry tomatoes, Hibiscus and crotalaria for improved health and nutrition in Uganda.

2.5.2. Project Objectives

- To enhance the productivity of turmeric, parsley, Cherry tomatoes, Hibiscus and Crotalaria in an advanced smart farming system.
- To develop a diversity of functional products from Turmeric, Parsley, Cherry tomatoes, Hibiscus and Crotalaria.
- To improve the concentration of primary and secondary metabolites in Turmeric, Parsley, and Cherry tomatoes, Hibiscus and Crotalaria.
- To build the capacity of key stakeholders within the value chain involved in the smart farming of turmeric, parsley, Cherry tomatoes, Hibiscus and crotalaria in Uganda.
- To promote environmentally sustainable practices within the smart farming system for Turmeric, Parsley, Cherry tomatoes, Hibiscus and Crotalaria

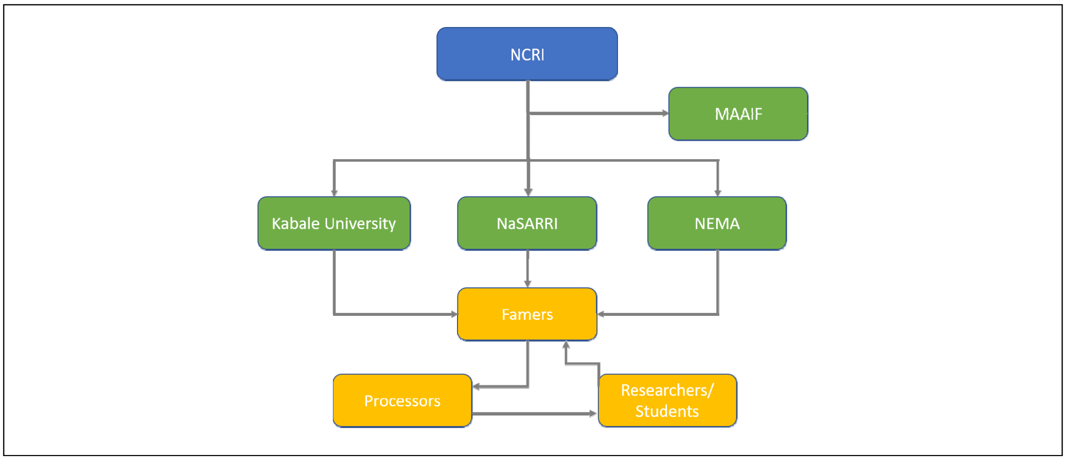
2.5.3. Project Governance



2.5.4. Project Implementation Plan

The implementation of the project will be coordinated by the NCRI. However, the project will establish the steering committee comprising of heads of the implementation organization. The steering committee will offer governance of the project. Each project implementing organization will identify of the staff to coordinate the respective project activities in their institution. The coordinating staffs make the technical advisory committee for the project. The NCRI will recruit a focal person to manage the operation of the project activities.

〈Figure 4-1〉 Project operation structure



〈Table 4-1〉 Responsibilities of implementing organizations

Recipient organization	Roles and responsibilities in the project
NCRI	• Coordination and support supervision of the project • R & D in product formulations and processing • Training and mentorship of processors on GMP and GAP
NaSARRI	• Research and development (crop breeding) • Training farmers on good agricultural practices (GAP) • Outreach activities and conducting field experimentation
Kabale University	• Training of students and researchers • R &D, training modules development, elicitation experiments
NEMA	• Regulation on environmental compliance • Training on environmental related aspects

〈Table 4-2〉 Project recipient organizations

Recipient organization	Roles, mandates and responsibilities	Status	Risk factors
NCRI	• Research and Development organization under the Ministry of Health. • NCRI promotes growers, processors and commercializing entities involved in production of products from plants of therapeutic and health benefits in collaboration with other government institutions like the National Agricultural Organization (NARO) and the National Forestry Authority (NFA).	Government	Few research equipment which are overused
NaSARRI	• Undertake research in crop production for semi-arid systems.	Government	
Kabale University	• Responsible for capacity building and research	Government	
NEMA	• Responsible for the monitoring, coordinating, supervising and regulating the natural environment and the environmental policy of Uganda. • NEMA Monitors and assesses activities, including activities being carried out by relevant lead agencies, in order to ensure that the environment is not degraded by such activities. • Management objectives must be adhered to and adequate early warning on impending environmental emergencies is given.	Government	

2.5.3. Legal Status of project implementing organizations

NCRI is a government research and development institution under the Ministry of Health. The institution undertakes the development of quality natural products and services for improved health care delivery by applying both indigenous and modern technologies. Its mandate is to conduct research on natural products and traditional medicine systems in treatment and control of human diseases and to justify their therapeutic claims.

NaSARRI is one of the Public Agricultural Research Institute of National Agricultural Research Organization (NARO), a corporate body by the National Agricultural Research Act of 2005. NaSARRI's mandate is to undertake research in crop and animal production for semi-arid systems. The operation area covers the cattle corridor and five others agro- ecological zones comprising the Eastern Savanna (Teso) region, Karamoja dry lands, Lango, Acholi and west Nile sub region.

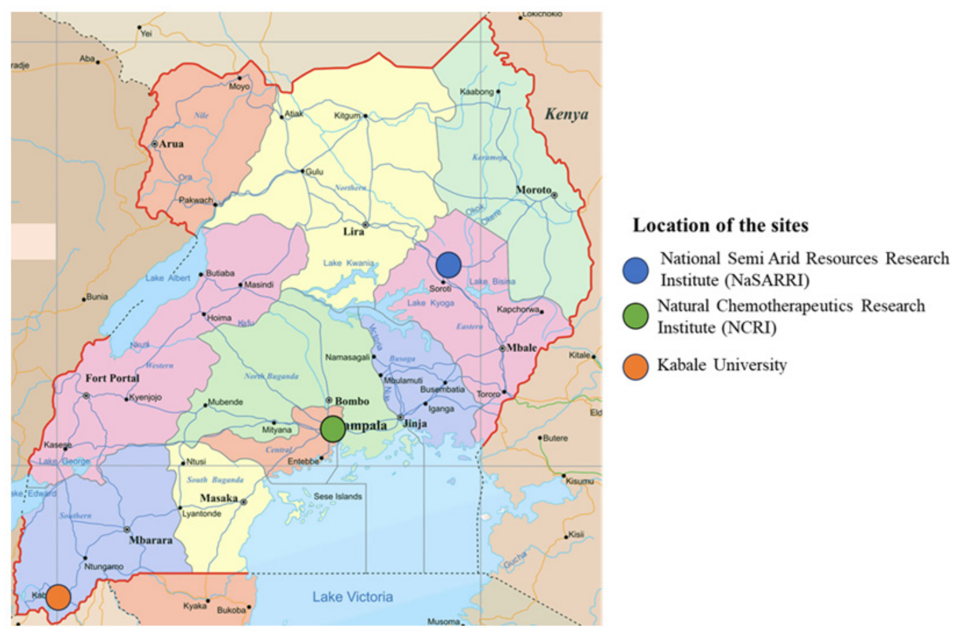
Kabale University is one of the Public Universities in Uganda. As a public University, Kabale University Universities and other Tertiary Institutions Act, 2001 is mandated to among others: a) provide higher education, promote research and provide advancement of learning; and (b) disseminate knowledge and give opportunity of acquiring higher education to all persons including persons with disabilities wishing to do so regardless of race, political opinion, colour, creed, or sex; (c) provide accessible physical facilities to the users of the Public University. NEMA is a semi-autonomous institution, established in May 1995, as the principal agency in Uganda, charged with the responsibility of coordinating, monitoring, regulating and supervising environmental management in the country.

2.5.4. Map of target country and project sites

The project is to be implemented in three project sites in Uganda, namely: Natural Chemotherapeutic Research Institute (NCRI), National Semi Arid Resources Research Institute (NaSARRI), Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Ministry of Health and Kabale University. The NCRI is a government institute created under the Uganda National Health Research Organization (UNHRO) Statute of 2011 with a mandate to conduct research in natural products and traditional methods in treatment and control of human diseases. NCRI is located in Kampala, the capital city of Uganda.

NaSARRI is one of 16 Public Agricultural Research Organization (NARO) of Uganda, located in the Eastern Agro-Ecological Zone of Uganda in Serere district, 300km from Kampala. The risk factor associated with Kabale University is the distance from the capital city, Kampala. Kabale University (KAB) is a Public University, fully owned and governed by the Government of the Republic of Uganda located in South western Uganda, 410km from Kampala. The major objective of KAB is to contribute to the socioeconomic development of Kigezi, Uganda, East Africa, and Africa through accessible training, research, and decentralized service delivery, using participatory and inclusive approaches and methodologies.

〈Figure 4-2〉 Map of the project sites



2.5.5. Feasibility of the Project

In regards to the proposed project, the expected result will be achieved due to; presence of existing policies and regulations that govern and monitor smart farming technology as well as support its application in Uganda, there is available land on which smart farming can be carried out. With some variation to the structure and material used, green houses can be constructed and maintained which makes the economic feasibility aspect viable.

Technical expertise which includes but is not limited to software development in relation to Smart farming facilities, knowledge of the different types of smart farms and available trained human resource in smart farming technology is available. The selected functional plants have application as both food and medicine making them relevant to both the pharmaceutical industry, food processing and cosmetic industry and to the overall objective of this project.

2.5.6. Compatibility on SDG's indicators

According to the SDG Global index, this project will contribute towards productive employment and decent work for women and men, including for young people and persons with disabilities, and equal pay for work of equal value (SDG 8). This project will also strengthen the prevention and treatment of diseases using functional foods (SDG 3). This project will enhance scientific research, upgrade the technological capabilities of agricultural industrial sectors in Uganda by encouraging innovation and substantially increasing the number of research and development of functional plant resources (SDG 9). This project will integrate ecosystem and biodiversity values into national and local planning, development processes and poverty reduction strategies (SDG 15). This project will implement their official development assistance commitments, targeting at least 0.20 percent of ODA/GNI to least developed countries (SDG 17).

This project will aim to double the agricultural productivity and incomes of small-scale food producers, in particular women, family farmers through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment (SDG 2). The project will integrate climate change measures into national policies, strategies and planning (SDG 13).

Uganda is performing averagely with moderate performance in regards to economic growth and employment (SDG 8), Industry, Innovation and Infrastructure (SDG 9), Good health and wellbeing (SDG 3), life on land (SDG 15), climate action (SDG 13) and partnerships for goals (SDG 17).

As a nation, Uganda has stagnated in regards to zero hunger (SDG 2) and Gender equality (SDG 5) and has made a small and unsteady improvement in relation to its Statistical Performance Index (SPI). Out of the 232 global indicators, only 202 are relevant to Uganda with the capacity to compile 85 out of the 202 global indicators. The SDG on climate action (SDG 13) has the highest score with available data scoring 100% Economic growth and employment (SDG 8) in specific on sustaining high GDP growth and a focus on high economic productivity as well as reducing the number of youths not in employment is compatible with objective 1 and 2 of this project. SDG 3 concerning good health and well being is in line with the first objective of this proposed project.

SDG 9 on sustainable industrialisation ties in with objective 2 of this proposal while SDG 17 ties in with the collaboration of the Uganda Government as represented by the different Institutions as outlined in this document and the Korean Government as represented by KREI.

2.5.7. Lessons learned from past projects by implementing organisations

- Improved peanut varieties can significantly increase yields in farmers' fields and the resultant benefits

- Participatory Varietal Selection (PVS) that involves both growers and traders ensures that varieties are tailored to meet requirements for both household food security and for markets
- Early bulking of groundnuts materials pre-releases is a good practice to avert seed and grain crisis post-release
- The use of various media tools in the dissemination of research outputs, constraints and opportunities is important is disseminating project information, successes, opportunities and challenges
- Agricultural shows, seed fairs, field days and farmers visits are very good for knowledge sharing and information dissemination
- There is a need for germplasm conservation for current and future uses
- Screening new maize varieties against predominant pests and diseases are very important for the introduced commodities from outside Uganda
- Availability of the crop improvement teams, available land and equipment, and access to irrigation are needed for any project implementations
- There is a need to build partnerships with diverse development partners. We observed this in Medicinal plants and Biodiversity Project funded by IDRC-Canada
- Contingency planning in light of new stresses (pests, diseases, drought, heat) and risks is key for project successes
- The sustainability matrix should be planned before project inception. This should be done alongside exit strategies
- Appreciation of cultural, social and gender dynamics is key at the project planning and monitoring
- The project should also evaluate the potential risks, and unintentional harm the projects intervention might likely produce
- Project objectives must be aligned with both the development partners interests and the implementers governing laws, mission, vision and goals
- Production need to be guided by consumer demands and markets

- This project targets array of beneficiaries which includes;
  - Farmers. These are primary producers of the raw materials from functional resources.
  - Researchers. These will be drawn from Ministry of educations (Academia: Kabale University, Makerere University), Ministry of Agriculture Animal industries and Fisheries (The National Agricultural research/organization), Ministry of Health (National Chemotherapeutic Research Institute), Ministry of Water and Environments (National Environmental Management Authority), Ministry of Trade and Commerce
  - Traders. These includes the suppliers of inputs (seeds, pesticides) and equipment used in the fields and those used by last miles users and processors
  - Processors: These are the categories of the stakeholders who add value to the raw materials. These includes factories both at the cottages and large-scale ones

The problems identified include; pests and diseases, high cost of inputs, poor infrastructure- low yield, poor infrastructure, poor quality of inputs and short shelf life of produce among others. The challenges identified by farmers in the production of the crops included; limited space, expensive plant materials, theft of the products and limited time to monitor (mushrooms), and limited market, unfavorable climate/weather, pest and diseases and birds (cherry tomatoes). The suggested solutions to address these challenges included; harvesting small to avoid overstocking and purchasing culture/media and spores in bulk (mushrooms), identify the niche market, provision water sources and use pesticides and grow in greenhouses (for cherry tomatoes). Turmeric had limited market. Other challenges and solutions are listed in the table below:

2.5.8. Project Logical framework

❍ Project expected outcomes and indicators

S/No	Expected Outcomes	Indicators
1	Improved livelihood	• Household incomes
2	Improved food security	• Household incomes • Yield of the crops
3	Improved health	• Trend of disease burdens
4	Improved infrastructure and farming practices	• Yield of the agricultural crops • Increased production cycle of the crops
5	Healthy and sustainable environment	• Quality of the discharge from the smart farm system - Health of the workers

❍ Project expected outputs and indicators

S/NO	Expected Outputs	Indicators
1	Increased productivity of Turmeric, Parsley, Cherry tomatoes, Hibiscus and Crotalaria	• Percentage increase in yield per hectare
2	Diversified and sustainable livelihoods through functional products	• Number of products from Turmeric, Parsley, Cherry tomatoes, Hibiscus and Crotalaria in the market • Type of products in the market from the Turmeric, Parsley, Cherry tomatoes, Hibiscus and Crotalaria in the market.
3	Improved concentration of primary and secondary metabolites in the targeted crops.	• Concentration per unit weight of the various crops.
4	Improved capacities of value chain stakeholders.	• Percentage increase in the number of stakeholders trained • Number of smart facilities established in the country. • Smart farming training modules developed in the institutions
5	Environmentally sustainable practices.	• Number of farmers compliant with sustainable practices. • Number of farmers trained in good environment practices

❍ Project expected results

Goal and Objectives	Indicators	Means of Verification	Assumptions
Goal: Establish integrated and sustainable agriculture in Uganda through advanced smart farming and innovative processing of turmeric, parsley, and cherry tomatoes.	Adoption of smart farming practices	Project reports	Adequate stakeholder engagement
Objective 1: To enhance the productivity of Turmeric, Parsley,	Increased yield per hectare	Field assessments	Availability of necessary

Goal and Objectives	Indicators	Means of Verification	Assumptions
Hibiscus, Crotalaria and Cherry tomatoes using advanced smart farming system			technology
Objective 2: To diversify functional products derived from Turmeric, Parsley, Hibiscus, Crotalaria and Cherry tomatoes through innovative processing methods.	Number of new product offerings	Sales records	Market demand for functional products
Objective 3: To improve the functionality of secondary metabolites in Turmeric, Parsley, Hibiscus, Crotalaria and Cherry tomatoes for improved health and nutritional benefits	Improved nutritional content	Laboratory analyses	Adherence to recommended farming practices
Objective 4: To strengthen the capacity of key stakeholders in the production and processing of Turmeric, Parsley, Hibiscus, Crotalaria and Cherry tomatoes in Uganda	Number of stakeholders trained	Training attendance records	Active participation of stakeholders
Objective 5: To promote environmentally sustainable practices in the production and processing of Turmeric, Parsley, Hibiscus, Crotalaria and Cherry tomatoes.	Reduction in environmental impact	Environmental assessments	Adoption of sustainable farming methods

2.5.9. Work plan and time frame

Activity	2026	2027	2028	2029
Establish smart farming facilities and research institutes				
Breeding high yielding functional crop varieties				
Developing optimum agronomic practices on functional crops				
Market survey to identify consumer preferences and trends				
Formulating function products for the markets				
Establish functional Agricultural Processing Center				
Developing standards for processing of the targeted functional crops				
Evaluation of bioactive components in the functional crops				
Conducting elicitation experiments in smart farm green houses				
Training programs for various stakeholders on smart farming on targeted crops				
Establish and equip a Centralised R and D laboratory on functional crops				
Conducting environmental baseline analysis				

2.5.10. Budget plan

S.No	Activities	Budget estimate (USD)
1	Establish smart farming technologies facility in research institution	1,100,000
2	Breeding of high yielding functional crop varieties in smart farm facilities	900,000
3	Develop optimum agronomic practices for functional crops	100,000
4	Establish an analytical laboratory for functional crops one research institute	1,000,000
5	Conducting survey to identify consumer preferences of functional crop products	150,000
6	Establish functional Agricultural Processing Center (APC) facilities for functional crops	500,000
7	Developing standards for processing of the targeted crops.	50,000
8	Conducting Laboratory experiment on bioactive ingredients in functional crops	500,000
9	Elicitation treatment experiments in green houses to improve the bioactive ingredient in green houses	250,000
10	Training programs for various stakeholders on smart production and processing	200,000
Grand total		**4,750,000**

2.5.11. Monitoring and evaluation plan

- The participating Institutions will use the existing Inhouse M&E infrastructure financial and technical evaluation
- The breeding success will be measured by the varieties and their products in market
- The Formulation of products will be monitored and evaluated by numbers of products formulated and registered and is in use
- The training of stakeholders will be monitored and evaluated by the manual and curriculum developed, number of stakeholders trained, number of students graduating on the programs, numbers of researchers trained and number of publications produced by scientists
- The project will also invite an independent M&E at mid-term and end term of the project

2.5.12. Communications plan among all stakeholders

The project will organize regular project meeting to discuss project implementation progress and project financial approvals. Steering committee meetings will be called upon by the Director of NCRI. There will also be technical advisory meeting organized for the principal investigators of the project implementing organizations. This meeting will be called upon by the project focal person and will discuss the on-going implementation of the project and suggest and changes that will be forwarded to the steering committee meeting. The principal investigators of the project will call weekly meetings with their technical staff to discuss implementation of the project. Once a year, the Director of NCRI will organize a conference or a workshop to share finding of the project with various stakeholders.

❍ Project communication plan

Stakeholder	Communication method	Frequency	Responsibility
Project steering committee	meeting	Quarterly	Director NCRI
Technical advisory committee	workshop	Monthly	Project focal person
Project researchers	meetings	weekly/monthly	Principal investigators in respective institutions
Farmers	training	as agreed upon by the project PI	Project PIs
Researchers	conference workshops	Annually Quarterly	Project focus person Project focal person

2.5.13. Transition or Exit strategy

The project leaders will ensure that stakeholders own up to the project from the start by enshrining the project activities into current government co-funding in terms of existing government infrastructure. The project will also adopt improved varieties into mainstream farming systems and also adopt smart farming modules in to the agricultural training system curriculum. The project will also ensure compliance with existing government regulations and organize an exit disclosure workshop.

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