ISSN 2415-2838 (Online)

AFJRD

African Journal of Rural Development

African Journal of Rural Development

Editorial Secretariat
Makerere university, Main Campus
Kampala, Uganda
Email:info@afjrd.org
Tel:+256417713300
Web address:www.afjrd.org

ISSN 2415-2838
www.afjrd.org

African Journal of Rural Development (AFJRD)
Vol 7 Issue 1, 2022

Table of Contents

About the Journal

http://afjrd.org/jos/index.php/afjrd/about

Editorial: Issues and lessons on strengthening extension services delivery, entreprenueship and agricultural intensification in Africa Famring systems. i
Adipala E.

The institutional reforms in Agricultural Input distribution services in Uganda: A case of involvement of soldiers in input distribution in Uganda 1
Ochen, M., Kibwika, P., Kyazze, B.F., Mubangizi, N. and Malinga, G.M.

Influence of land tenure security on household food security among small holder farmers in Narok County, Kenya 20
Mbudzya, J. J., Gido, O.E. and Owuor, G.

Distribution of *Fusarium* spp. agents responsible for Fusarium Wilt of banana in Southern Benin 38
Toessi, H.G., Zandjanakou-Tachin, M., Brahima, C. and Daouda, K.

Evaluation of the bull scheme: An open nucleus breeding system in the communal livestock farming areas of Namibia 53
Marius, L. N., Togarepi, C. and Seibeb, I.

Entrepreneurial orientation, learning orientation, cost focus and innovation in agri-food SME of Uganda 68
Ajer, B., Ngare, L. and Macharia, I.

Fuel from the Farm: An analysis of the profitability and factors driving farmers' decisions to produce bioethanol from cassava in Northern Uganda 89
Opolot, D., Ilukor, J., Mukasa, S. and Mugisha, J.

Rainwater harvesting technologies: Adoption, maintenance, and limitations among smallholder farmers in drought prone areas of Uganda 111
Mfitumukiza, D., Barasa, B., Sseviiri, H. and Nyarwaya, A.

African Journal of Rural Development, Vol. 7 (1): January-April 2022 pp.i-iv. ISSN 2415-2838

Editorial

Issues and lessons on strengthening Extension service delivery, entrepreneurship, and agricultural intensification in African farming Systems

E. ADIPALA
Editor-In-Chief, African Journal of Rural Development
Corresponding Author: e.adipala@rae.co.ug

ABSTRACT
This Issue of African Journal of Rural Development includes seven papers addressing diverse topics: extension service delivery, promoting entrepreneurship in Agri-food Systems, land tenure, vermicomposting, livestock breeding, water harvesting, production of bioethanol from cassava and occurrence of devastating Fusarium wilt disease of bananas in Benin. These studies were conducted in different parts of Sub-Saharan Africa and do provide insights into some of the issues and research being conducted across the continent. More of such research findings need to be disseminated widely using various publication outlets.

Key words: Africa, cassava bioethanol, entrepreneurship, extension delivery, land use management, vermicomposting

RÉSUMÉ
Ce numéro du Journal africain de développement rural comprend neuf articles abordant des sujets divers : la prestation des services de vulgarisation, la promotion de l'entrepreneuriat dans les systèmes agroalimentaires, le régime foncier, le vermicompostage, l'élevage du bétail, la collecte des eaux, la production de bioéthanol à partir du manioc et l'apparition de la redoutable maladie de flétrissement fusarien des bananes au Bénin. Ces études ont été menées dans différentes régions de l'Afrique subsaharienne et apportent des éclairages sur certaines problématiques et recherches menées à travers le continent. Il est nécessaire de diffuser plus largement de telles découvertes de recherche en utilisant différents moyens de publication.

Mots-clés: Afrique, bioéthanol de manioc, entrepreneuriat, prestation de services de vulgarisation, gestion de l'utilisation des terres, vermicompostage

Recent statistics by the Food and Agriculture Organisation (FAO) indicate that the food security situation in Africa has worsened over the last 5-10 years compromising the gains made over the past years. Only a few countries appear food secure notably Tanzania and Malawi whose food security situation improved considerably compared to in previous years. Notable economies such as South Africa and Kenya record deficiency in food supply leading to increases in food imports. There are a multitude of factors contributing to the poor food supply in Africa, including unsustainable farming practices leading to low productivity, the increasing challenges posed by climate change and variability, the rapid increases in population growth, and the recent COVID pandemic, amongst other factors. The World and Africa in particular is aware of these challenges and have called for strategic interventions at different levels including policy, strengthening research and innovation capacity in the continent, harnessing global partnerships to strengthen agri-food systems in the continent, and promoting inclusivity in all undertakings. In this regard, strengthening practices at the smallholder farmers level is key since they produce the bulk of food in Africa. Ensuring smallholder farmers have the knowledge, information, skills and supportive infrastructure is thus key for enhancing increased productivity and sustainability of agri-food systems in Africa.

This Volume of the African Journal of Rural Development explores some of the issues above including possible needed interventions. The first paper by Ochen *et al*. (2022) discusses a long outstanding challenge confronting smallholder farmers across Africa: inaccessibility of quality extension support systems with only a few accessing extension services. The paper describes various initiatives that have been tried in Uganda to strengthen extension service delivery, the success and failures of the efforts including the recent engagement of military personnel as extension/input service providers. Several lessons can be drawn from these various efforts in Uganda key amongst which is that delivery of extension information accompanied by input and indeed credit provision is paramount. For effectiveness, strong farmer institutions that harnesses inclusivity need to be established and nurtured. Future interventions would need to foster broad gender participation and as much as possible take advantage of farmer friendly Information delivery services including use of Information Technologies.

The second paper also examines a major challenge confronting farming systems in Africa: Land tenure insecurity. The study done by Mbudzya *et al*. (2022) in Norok County in Kenya clearly shows that a secure tenure of agricultural land is key for enhancing sustainable productivity and for promoting investment in agricultural production systems. The study showed that land insecure households would increase their food security by 38% if they were land tenure secure. Similarly, in Malawi, Ajefu *et al*. (2020) showed that land tenure security enhanced coping against drought-induced food insecurity. Thus policies to enhance land tenure security are needed to enhance food and livelihood security of farming communities.

It is today recognized that promoting entrepreneurship in various facets of life is critical for competitiveness. The study by Ajer *et al*. (2022) done in Uganda explored issues of entrepreneurial orientation, learning orientation, cost focus and innovation in agri-food systems small and medium enterprises (SMEs) in Uganda. The study results indicate the need for enhancing learning orientation, cost focus and innovation. The study highlights the need to promote entrepreneurial proclivity to enhance entrepreneurial mindset, although not necessary innovation. A related study done in Malaysia is described by Akbar *et al*. (2020). Opolot *et al*. (2022) examined profitability and factors driving farmers' decision to produce bioethanol from cassava. As eluded to earlier strengthening entrepreneurship mindset and practices is key for turning livelihood activities into business opportunities and for increasing incomes of households.

Subsequent papers in this Volume examine some production contraints hampering crop production in Africa. Toessi *et al*. (2022) describes and maps out the increasing occurrence of Fusarium wilt (Panama disease caused by *Fusarium oxysporum* f.sp *cubense* (E.F Smith) disease of bananas in Southern Benin where the disease is deciminating banana production as it has done in several other countries. The disease is widespread in East and Central Africa especially in Uganda (Tushemeirwe *et al.,* 2000; Oyesigye *et al.,* 2021; Anouk *et al.,* 2022). Collaborative research needs to be intensified to address this spreading disease problem.

The paper by Mfitumukiza *et al*. (2022) examines adaptation and factors limiting use of rainwater harvesting technologies amongst smallholder farmers in Uganda. The findings indicate that most rainwater harvesting techniques used roof surfaces for water catchment which was channeled into storage facilities for domestic and production purposes. Clearly there is need to promote rainwater harvesting for production as well as for home use. Research is also needed to enhance safety of the harvested water.

The final paper in this Volume by Marius *et al*. (2022) presents results of an initiative that is establishing an open nucleus communial livestock breeding system in Namibia

In conclusion, this Issue of AFJRD presents a diversity of papers that provide insights on some challenges and opportunities for sustainable agricultural intensification, opportunity for instilling agribusiness mindset in Agri-food systems and options and lessons for strengthening farmer extension service delivery. There are related works being done across the continent and we need to share the findings widely.

ACKNOWLEDGEMENT
I thank the authors of the papers presented in this Issue for sharing their research findings and insights with the wider community.

REFERENCES

Ajefu, J.B. and Abiona, O. 2020. The mitigating impact of land tenure security on drought-induced food security: Evidence from rural Malawi. *Journal of Development Studies* 56 (12): 2169-2193.

Ajer, B., Ngare, L. and Macharia, I. 2022. Entrepreneurial orientation, learning orientation, cost focus and innovation in agri-food SME of Uganda. *African Journal of Rural Development* 7 (1): 68-88.

Akbar, F., Khan, R.A., Wadood, F. and Bon, A.T. 2020. Entrepreneurial orientation dimension affects firm performance: A perspective from the Malaysian furniture industry. *Entrepreneurial Business and Economics Review* 8 (4): 157-181.

Anouk, C. van Westehovan, Hanold, J.G. Meijer, Saidi M.F., Gart, H. and Koma, J. 2022. Uncontained spread of Fusarium Wilt of bananas threatens African Food security. *PLoS Pathog* 18 (9): e10709.

Marius, L. N., Togarepi, C. and Seibeb, I. 2022. Evaluation of the bull scheme: An open nucleus breeding system in the communal livestock farming areas of Namibia. *African Journal of Rural Development* 7 (1): 53-67.

Mbudzya, J.J., Gido, E.O. and Owuor, G. 2022. Influence of land tenure security on household food security among small holder farmers in Narok County, Kenya. *African Journal of Rural Development* 7 (1): 20-37.

Mfitumukiza, D., Barasa, B., Sseviiri, H., Nyarwaya, A., Mwesigwa, G.Y. and Kiggundu, N. 2022. Rainwater harvesting technologies: Adoption, maintenance, and limitations among smallholder farmers in drought prone areas of Uganda. *African Journal of Rural Development* 7 (1): 111-132.

Ochen, M., Kibwika, P., Kyazze, B. F., Mubangizi, N. and Malinga, G. M. 2022. The Institutional dynamics in agricultural input distribution services. A case of military participation in input distribution in Uganda. *African Journal of Rural Development* 7 (1):1-19.

Opolot, D., Ilukor, J., Mukasa, S. and Mugisha, J. 2022. Fuel from the Farm: An analysis of the profitability and factors driving farmers' decisions to produce bioethanol from cassava in Northern Uganda. *African Journal of Rural Development* 7 (1):89-110.

Oyesigye, E., Tinzara, W., Karamura, G. and

Cosmas, W. 2021. Distribution and Farmer knowledge of Fusarium Wilt (Race 1) in cropping systems in Uganda. *African Journal of Agricultural Sciences* 15 (11): 277-287.

Toessi, G. H.., Zandjanakou-Tachin, M., Brahima, C. and Kone D. 2022. Distribution of Fusarium Species agents responsible for Fusarium Wilt of banana in Southern Benin. *African Journal of Rural Development* 7 (1): 38-52.

Tushemeirwe, W.K., Kangire, A., Kubira, J. and Namakunda, K. 2000. Fusarium wilt resistant bananas considered appropriate replacements for cultivars susceptible to the disease in Uganda. *Uganda Journal of Agricultural Sciences* 5: 62-64.

African Journal of Rural Development, Vol 7(1) January-April 2022: pp.1-19. ISSN 2415-2838

The institutional reforms in Agricultural Input distribution services in Uganda: A case of involvement of soldiers in input distribution in Uganda

M. OCHEN, P. KIBWIKA, B.F. KYAZZE, N. MUBANGIZI and G.M. MALINGA
Department of Extension and Innovations Studies, College of Agricultural and Environmental Sciences, Makerere University, P.O. Box 7062, Kampala, Uganda
Corresponding author: morrishochen@gmail.com

ABSTRACT

This paper analyses different institutional reforms in the agricultural inputs' delivery services and how the reforms contributed to the evolution of the current Operation Wealth Creation (OWC) program in Uganda. A community-based research approach was used. The study interviewed 43 key policy actors in agricultural inputs distribution services. Findings indicate that many reforms were implemented but alternated between two major approaches; i) when inputs and advisory services were fused up and delivered as a package, and ii) when inputs and advisory services were delivered separately by the extension agents. The different phases are categorised as; Regulatory (1922-1956) and Educative (1957-1971) phases, where inputs and advisory services were fused; Advisory (1992-2013) and Single Spine (2014-to date) phases, where inputs and advisory services delivery got separated. In all the approaches, the services lacked proper coordination, and in some cases no institutional frameworks to guide the extension services leading to ineffectiveness. Furthermore, some of the strategies used e.g coerciveness as a tool for advisory services under Regulatory phase and separating inputs from advisory services in the later Advisory phase set a favourable ground for involvement of the soldiers to specifically handle input delivery under OWC program. It is practically impossible to separate input delivery from advisory services if effective agricultural transformation is to be achieved at farmers' households. The findings are important in unveiling the inherent challenges in input delivery in Uganda and guiding policy decisions on appropriate reforms in the agricultural input delivery to poor farmers. Limited information is available regarding the appropriate agricultural institutional reform that can be effective and sustainable in the country.

Key words: Agricultural inputs, extension services, institutional frameworks, NAADS, Operation Wealth Creation, Uganda

RÉSUMÉ

Cet article analyse différentes réformes institutionnelles dans les services de distribution des intrants agricoles et comment ces réformes ont contribué à l'évolution du programme actuel Operation Wealth Creation (OWC) en Ouganda. Une approche de recherche communautaire a été utilisée. L'étude a interrogé 43 acteurs clés de la politique dans les services de distribution des intrants agricoles. Les résultats indiquent que de nombreuses réformes ont été mises en œuvre, mais ont alterné entre deux approches majeures : i) lorsque

Cite as: Ochen, M., Kibwika, P., Kyazze, B. F., Mubangizi, N. and Malinga, G. M. 2022. The Institutional dynamics in agricultural input distribution services. A case of military participation in input distribution in Uganda. *African Journal of Rural Development* 7 (1): 1-19.

Received: 14 January 2021
Accepted: 17 October 2021
Published: 30 April 2022

les intrants et les services de conseil étaient fusionnés et livrés en tant que package, et ii) lorsque les intrants et les services de conseil étaient livrés séparément par les agents de vulgarisation. Les différentes phases sont classées comme suit : les phases Réglementaire (1922-1956) et Éducative (1957-1971), où les intrants et les services de conseil étaient fusionnés ; les phases de Conseil (1992-2013) et de Single Spine (2014 à ce jour), où la livraison des intrants et des services de conseil était séparée. Dans toutes les approches, les services manquaient de coordination adéquate et, dans certains cas, il n'existait aucun cadre institutionnel pour guider les services de vulgarisation, ce qui entraînait une inefficacité. De plus, certaines des stratégies utilisées, telles que la coercition comme outil de services de conseil dans la phase réglementaire et la séparation des intrants des services de conseil dans la phase de conseil ultérieure, ont créé un terrain favorable à l'implication des soldats pour gérer spécifiquement la livraison des intrants dans le cadre du programme OWC. Il est pratiquement impossible de séparer la livraison des intrants des services de conseil si une transformation agricole efficace doit être réalisée au niveau des exploitations agricoles des agriculteurs. Les résultats sont importants pour dévoiler les défis inhérents à la livraison des intrants en Ouganda et guider les décisions politiques concernant les réformes appropriées dans la livraison des intrants agricoles aux agriculteurs pauvres. Les informations disponibles sont limitées concernant les réformes institutionnelles agricoles appropriées qui peuvent être efficaces et durables dans le pays.

Mots-clés : Intrants agricoles, services de vulgarisation, cadres institutionnels, NAADS, Operation Wealth Creation, Ouganda

INTRODUCTION

World over, agricultural extension services have been greatly criticized for being inefficient, costly and outdated especially in developing countries (Feder *et al.,* 2010; USAID, 2015; Barungi *et al.,* 2016). Yet, without doubt, the delivery of agricultural extension services has been proven to play a critical role in improving households' production and productivity that can guarantee food and income security for the rural poor resourced farmers. It is through extension services that farmers are not only provided with high yielding modern inputs but also knowledge on how best to manage the inputs for better results. In principle therefore, agricultural extension services comprise two major roles; (i) input delivery, and (ii) advisory services roles. Of late, the advisory services have been extended into aspects of guiding farmers on group formation, farming as a business, value addition and agro-processioning, marketing and enterprise developments, all of which offer a comprehensive support for a farmer to produce enough for consumption and the extra for incomes. Birner (2011) in a study of the NAADS program does illustrate the strong complementary roles between inputs delivery and advisory services if effective input delivery is to be achieved and further guided on the strong need to incorporate households' characteristics of farmers, including taking into account the competencies and skills of extension agents that are involved.

The pathways demonstrate the interplay between inputs and advisory services components in ensuring better choices of quality inputs for effective production and incomes. Despite the views expressed in the pathways (Fig1), what has remained contentious among policy makers and technocrats is the question of whether the input and advisory services roles could be disjointed from each other and separately delivered or should instead be fused up and delivered as a package by the extension agents. The arguments, coupled with limited study, has been the major root cause of several reforms in extension services in developing countries.

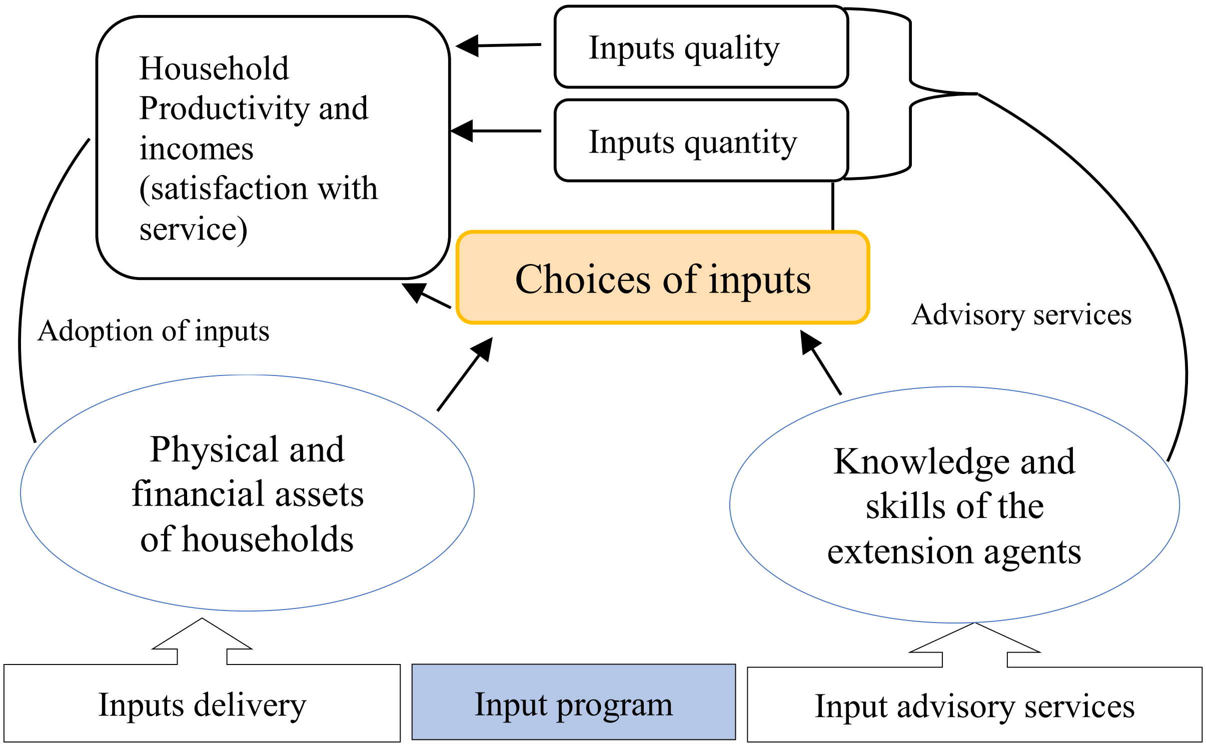


Figure 1. Effective input and advisory services pathways as modified from Birner (2011)

Agricultural extension reforms and development. Efforts to reform agricultural extension services in developing countries were aimed at benefiting the poor farmers who constituted the majority of the population but relied on subsistence farming for their livelihoods. Developing countries perceived that improving farmers' production and productivity through provision of quality inputs and necessary information was one of the best strategies for poverty reduction campaigns that had dominated the Government agenda at that time (Barungi *et al*., 2016). In part was the fact that Official Development Assistance (ODA) towards agricultural extension services in Africa (especially South of Sahara) contributed 57% of total aid in the 1990s and 2000s, which was a motivation to governments to focus on extension services in addressing the needs of the poor (Nederlof *et al*., 2011; FAO, 2015).

The 1990s and 2000s also witnessed a period of strong advocacy for private sector involvement in the provision of services to the citizen, characterized by frequent calls from World Bank, IMF and other donors for liberalization of the economies, opening up of markets and empowerment of citizens to demand for services of their interests. Extension service as a key sector was targeted, and development partners quickly engaged governments to allow private sector involvement including other innovative steps in the provision of agricultural inputs and advisory services as demanded by farmers. In 2005, in Vietnam, DANIDA, a development arm of the Danish Government instituted a separate livestock input delivery systems from the traditional government approach. Separate as it was from advisory services, policy makers and farmers questioned whether the new livestock input delivery intervention would have done much better if fused into the mainstream extension services or if executed through farmers' organizations for effective outputs, monitoring and acceptability (Jens *et al.,* 2005). Indonesia, on the other hand had earlier on taken a much radical step (under the new order era of the Soeherto regime) to deploy soldiers to distribute inputs to farmers, while advisory services could be undertaken by qualified extension workers. The Indonesia case is documented as one of the successful extension reforms involving soldiers in input distribution in which rice production more than tripled (4,293,000 to17,156,00 metric tones), and was recognized and awarded certificate of self-reliance by Food and Agricultural Organization (Mirojul *et al.,* 2016). The Vietnam and Indonesia cases are examples of some of the many reforms by developing countries that were undertaken in an attempt to get the best approaches that could effectively deliver inputs to farmers, a struggle that kept extension services in transitions.

Agricultural Extension services reforms in Uganda. The agricultural extension reforms in Uganda dates back to the early 1920s when the British colonial masters begun the process of organizing and guiding farmers to produce materials for their industries back in Britain (Semana *et al.,* 2018). Over the decades that followed, many reforms were undertaken, and implemented but with limited success following widespread complaints from stakeholders on quality of inputs delivered, competencies of the extension agents, lack of or inappropriate policies, corruption, poor infrastructures, inadequate staffing and funding among others (Rivera and Qamar, 2003; Barungi *et al.,* 2016; Semana *et al.,* 2018). The latest reform, the Operations Wealth Creations (OWC), was a stop gap measure by the President of Uganda in 2013, deploying soldiers to spear head input distribution to farmers (MoD and VA, 2014; OPM, 2015). Soldiers were deployed based on the trust the President had in them as officers who are incorruptible, patriotic and able to execute orders to the dot. Deploying soldiers would not only cure the inefficiencies in the previous approaches as outlined, but because the soldiers have successfully executed other assignments in other sectors where they are engaged, including outstanding outputs such as construction of health and education facilities, disaster and risk management (floods, water weeds, locust invasion, disease epidemics), eliminating rebels' activities in and outside the country among others

Just as in other developing countries, one critical contentious issue in the designs of these reforms was the question of whether inputs and advisory services roles could deliver a fused or separate roles. How these separation or fusion aided effective input delivery to the satisfaction of stakeholders and how the designs precipitated the evolution of the latest reform (OWC) in Uganda has not been adequately documented. This study aimed at contributing to this knowledge by reconstructing and analyzing the different institution reforms and approaches on input distribution in Uganda, the perceived good practices and mischief in the reforms, including the accompanying frameworks and how they could have contributed to the current OWC program in the Country. The paper concludes by providing policy options that can improve the efficacy of the current inputs distribution services to smallholder farmers in Uganda.

METHODOLOGY

Participants, sampling and data collection. The paper is based on three main types of data sources; i) published information relating to inputs distribution reforms and frameworks in Uganda (policy documents, research reports including other relevant published literature), ii) participants' observations by the researchers and iii) Interviews and focus group discussions with selected key informants and farmers involved in inputs distribution in Uganda with a major focus on Operation Wealth Creation (OWC). The key informant interviews and FGDs were mainly aimed at obtaining facts on the events, and their views and perceptions on the input distributions processes in Uganda since the 1920s. The study involved 43 policy stakeholders with demonstrated experience in the delivery of agricultural inputs services in Uganda as spelt out in (a) The Standard Order of Procedure (SOP) for OWC; (b) The National Agricultural Extension Policy, and (3) The National Agricultural Extension Strategy (MAAF, 2016).

In institutions where two respondents were purposely identified, one was from a strategic level to provide an understanding of the institutional reforms and frameworks while the other respondent was identified from the operational level to provide an insight on how the frameworks are applied in the field during inputs distribution processes to farmers. In the local government (Nakaseke district), out of a total of eight respondents purposively interviewed, two were from each of the sub-sectors of crops, livestock, fisheries and entomology, in which each subsector still had one respondent from the management and the other from operational levels. The respondents were interviewed using Key Informant Interviews (KII) guides prepared with approval from a team of six experts from Makerere and Gulu universities in Uganda.

The Focus Group Discussions (FGDs) involved two farmer committee groups, each comprising of nine purposively selected lead enterprise farmers from the sub-county farmers' committees. As guided by the local leaders and extension workers, the lead enterprise farmers (both men and women) had participated in the implementation of the OWC targeted enterprises (coffee, beans, maize, citrus, cows, goats, poultry) in the district for at least the last 3-5 years. The FGD interviews, moderated by the researcher using the FGD guides took an average of two hours. The respondents were interviewed to determine their perceptions towards the institutional reforms in the distribution of inputs services and how the frameworks shaped up the current inputs' distribution processes under OWC. The sub-themes in the guides included (i) evolution and performance of the institutional reforms and frameworks in inputs distribution in Uganda and (ii) how the different reforms eventually shaped up input delivery under OWC program.

Data analysis and tools. Responses were transcribed verbatim, while those in the local dialects of Luganda were first translated into English before importation into the Nvivo 12 plus software for thematic coding and analysis. By induction, open codes were assigned to clustered narratives in the responses. Each clustered response was created as a new node with an appropriate title. Through coding stripes, a word cloud analysis was performed to generate themes within the clustered responses

The Advocacy Coalition Framework Theory (ACF). This theory developed by Sabatier and Jenkins- Smith in the 1980s has proved a useful theory in explaining policy reforms and implementations processes in institutions (Sabatier and Jenkins-Smith, 1993). The theoretical framework is comprised of subsystems that have individuals and groups that constitute themselves into an "advocacy coalition". An advocacy Coalition is a group of individuals sharing policy beliefs and values about a policy under debate. Sabatier and Jenkins- Smith (1993) argue that beliefs and values guide individuals or groups' actions when it comes to decision making and can be used to map the relationships between various organizations within the policy subsystems. This in turn provides the causal theory upon which policy positions are constructed and later underpin the guiding instruments for operations. The policy subsystem is an element of the theory that refers to the interactions of the advocacy coalitions from different institutions that seek to influence governmental decisions towards a specific policy area. The assumption is that the subsystems contain a large number of actors from various public and private organizations actively concerned with a policy issue or problem. The subsystems arise because of a particular need or dissatisfaction with the existing debate or action with the view of causing a change or reform (Semana *et al*., 2018).

For this study, the Advocacy Coalitions are grouped into two main categories; the "State Actor Coalition" and "Non-State Actor Coalition". The "State Actor Coalition" constituted majorly the government bureaucrats mainly professionals in Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and Local Governments, Academia, Research Institutions who promoted the maintenance of the traditional agricultural inputs' distribution services. The "Non-State Actor Coalition" comprised the development partners including World Bank, IMF, IFAD, CSOs and the farmers who pushed for a change in the way extension services including inputs distributions were being delivered.

RESULTS AND DISCUSSIONS

Institutional reforms in agricultural input distribution in Uganda

Regulatory Phase of Extension Services (1922-1956). Agricultural extension services in the regulatory phase began around colonial times (1897-1907) with the importation of cash crops planting materials such as cotton, coffee, cotton and rubber as prioritized by Britain for its industries (Semana, 2002; Barungi *et al.,* 2016). Despite limited knowledge, the chiefs were the "extension experts" who institutionalised coercion as an extension approach. The relationship between input delivery and advisory services could not be easily delineated, demonstrating some kind of unclear input and advisory services delivery approach to farmers. The regulatory phase was not effective in delivering inputs and advice to farmers because other than relying on instructions from colonial leaders, there were no appropriate policies to govern extension services to farmers. Coercive instructions meant that farmers had limited chances to express themselves in the entire processes as alluded to by a member of the Public sector coalition group during KIIs;

"*The farmers had no voice over the entire extension processes because the chiefs were always right, executing 'orders from above', and therefore limiting effective participation of farmers*" (KII of April, 2019).

Not only in input delivery sector that the colonial leaders demonstrated their dominant views over the inferior African farmers who in this case, other than their labour and land had essentially nothing else to contribute. Pushing farmers to grow cash crops as prioritised by Britain was bound to compromise farmers' priority to produce food crops for their households, a process that likely affected the performance of the regulatory phase.

Educative Phase (1956-1971). This phase witnessed input and advisory services deliberately fused up and delivered as a package by extension agents. It focused more on building capacity of the farmers to be able to demand for the services, as was being advocated in the development paradigm at the time. Farmer's capacity was built through trainings in research institutions, district farms institute, village trainings sessions by extension agents, etc. Delivering inputs and advisory services as a package did not save the phase from being criticised and labelled as ineffective in aiding input access by the poor farmers. First, the phase had an ambitious plan of targeting the delivery of inputs and advisory trainings to all the households and yet the corresponding resources (extension workers and their facilitations) were not commensurate (Semana, 2002). Secondly, when the approach decided to use progressive farmers (1956-1963) to deliver inputs and advice to their colleagues, the progressive farmers were criticised for not only being a privileged group that utilised their positions to deprive others of the inputs provided by government, but also lacked the necessary knowledge to offer accompanying advisory services. This confusion caused a shift to another approach called the Training and Visit (T&V) implemented between 1964-1997 and heavily financed by the World Bank. The T&V required visiting the many farmers' households while offering both inputs and advisory services but also encouraging a two-way information flow missing in the previous extension approaches. With minimal lessons learnt from the progressive farmers' approach, resources in terms of available extension agents and the facilitations required to sustain the T&V proved inadequate. World Bank eventually pulled out, and the Government could not sustain the services due to little resources available. In view of all these findings, what was critical for farmers to access services was not necessarily the fusion of the inputs and advisory services delivered as a package in the reform, but the availability of qualified extension workers that were adequately facilitated to reach a section of farmers to transform their production.

The Dark and recovery Phases (1971- 1997). The period 1972-1979 was characterized by political turmoil rendering extension services inactive. The 1980s to 1997 was a recovery period in which the Government began to put in place basic infrastructures, capacity development efforts and legal frameworks to restore extension services in the country. In 1991, with support from World Bank, the Government undertook a unified extension approach to streamline the scattered efforts experienced in the 1980s. The unified extension approach also witnessed a fusion of input and advisory services implemented as a package. The approach required an extension worker to provide extension services in all the fields of crops, animals, entomology and fisheries, a strategy, which did not succeed due to unmatched training of the extension worker in all the above fields. The Unified Approach continued on the back ground of other extension services and approaches until 2014 when it was officially abolished.

The Advisory Services Phase (1997-2013). This phase was the most critical in setting up the extension agenda in the country for broadly four reasons; (i) Putting up the necessary institutional frameworks that guided inputs and advisory services delivery, (ii) advocating for the empowerment of farmers to demand for extension services of their choices, (iii) promoting the participation of the private sector, and (iv) witnessed the inputs and advisory services delivery roles being separated. This paper has, however, focused more on the analysis of the development of the institutional frameworks and implementation of the input and advisory services roles.

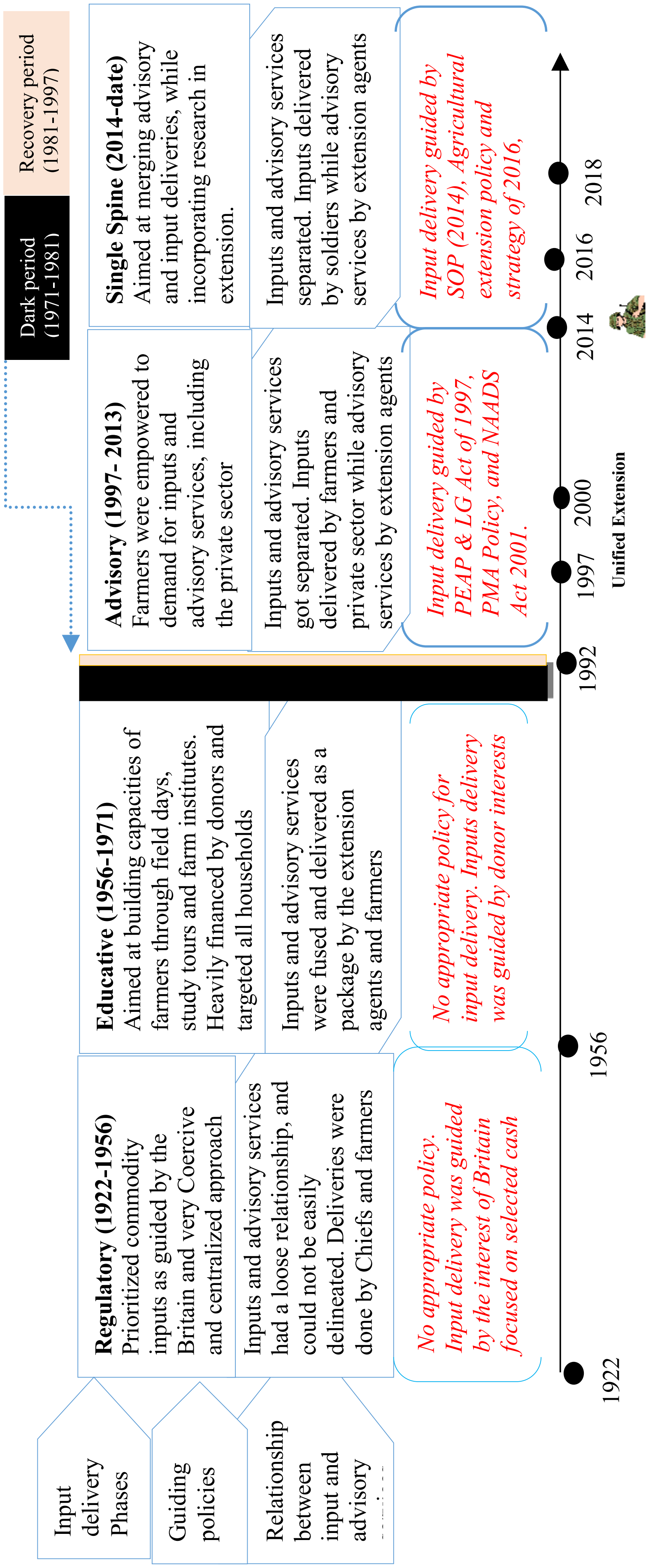


Figure 2. Reconstruction of the input institutional reforms

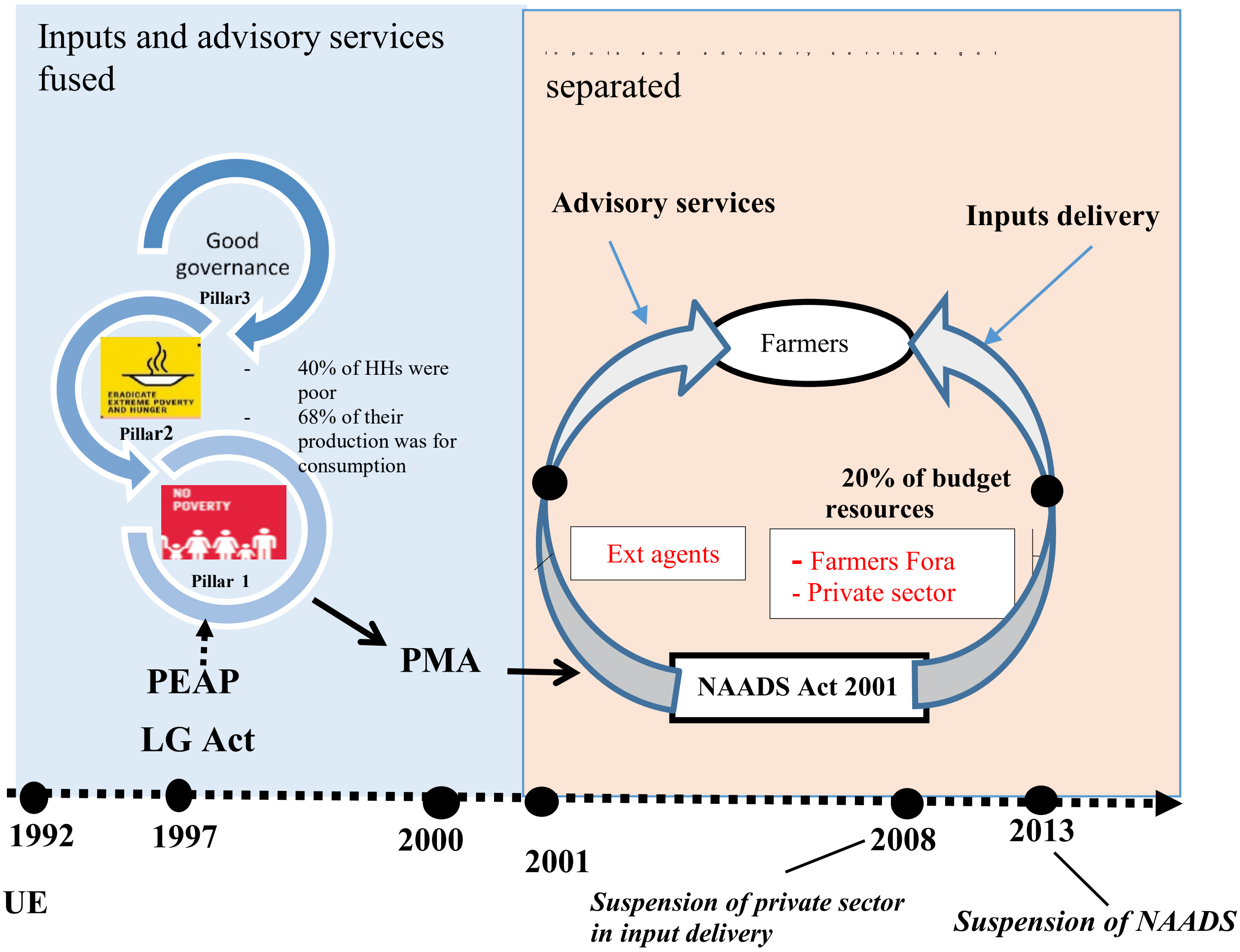


Figure 3. Policy reforms towards inputs and advisory services separation

In the early 1990s, the Government of Uganda like in other sub Saharan African countries undertook a deliberate effort to reduce poverty amongst the citizens, which by then stood at 40% with a weak GDP averaging $330 per person per year. To actualize this effort, a decentralised Poverty Eradication Action Plan (PEAP) was formulated in 1997 with three main pillars; first was to increase incomes of the poor people; secondly, improving living standards of the poor people and, thirdly to promote good governance. Therefore PEAP set a foundation for other policy reforms towards poverty reduction amongst poor people. In that context therefore, targeting the poor would mean reforming interventions in agriculture which formed the basis of their livelihoods. During that period, development partners such as World Bank vigorously engaged Government to carry out reforms that would favour neoliberal policies (Benin *et al.,* 2010). The neoliberal policies advocated for economic liberalization, free trade, open markets, privatization, deregulation and reduction in government spending to enhance private sector participation in the economy (Gerring and Stron, 2005). In response, a multi-sectoral program (Plan for Modernization of Agriculture- PMA) was developed in 2000 to address the obstacles scattered in the different economic sectors of the country to leverage agricultural transformation. The PMA aimed at reducing poverty from 56% in 1986 to 28% by 2014 within the framework of PEAP. It had seven critical pillars; technology development and research, national agricultural advisory services, agricultural education, agricultural infrastructure, agro-processing and marketing, sustainable natural resource utilization and improving access to microfinance. The implementation of PMA witnessed inputs and advisory services fused up and being delivered as a package to farmers but with the recurrent challenge of low agricultural productivity. The PMA performance review reports indicated that the low agricultural productivity observed in Uganda was not a consequence of lack of researcher extension activity as both had received adequate funding in the past (MAAIF, 2000), the low productivity of the Ugandan farmers was caused mainly by poorly functioning farmer-extension- linkages and the failure of the research to respond to the real needs of the farmers (MAAIF, 2000; PMA, 2000; MAAIF, 2016). The non-State actor coalition group pushed for a quicker reform within PMA program. On the other hand, members of the State Actor Coalition ganged against the proposed reforms arguing that it would be radical and it was the interests of the donors that were being pushed. Since it was heavily financed by the Word Bank, it became possible for the government to easily embrace the reform aware of the limited pressure on the locally generated resources. Agricultural advisory services, the second of the seven pillars of PMA came in handy as an intervention area for the reform, eventually leading to evolution of NAADS through the NAADS Act 2000. The NAADS act set the beginning of the separation of inputs delivery from advisory delivery services in Uganda.

The separation of Inputs and Advisory Services roles under NAADS. The NAADS Act (2001) and the implementation manual (2004) guided on separate advisory services and input delivery roles in the extension services to farmers (NAADS, 2004). In that guideline, advisory services were allocated more than 70% of the overall resources, while inputs took the balance of less than 30%. During its implementation, farmers took charge of the procurement of all advisory services and either delivered the services themselves or procured service providers to do so on their behalf. Extension workers employed by government were left to undertake the roles of quality assurance on input delivery services including setting up technology development sites for farmers. The NAADS believed in empowering farmers to demand for what they wanted as alluded to by one of the KIIs (April, 2019)

"There was a need for demand-driven processes to allow farmers to take control of the key processes in the extension system. This required that appropriate farmers' institutional structures be created that could merge with the formal extension structures. In this way, the formal processes would respond to what the informal (farmers) processes would generate, therefore seceding some powers to the farmers" (KII, April 2019).

In order to strengthen farmers' empowerment, NAADS operated through farmers' institutions referred to as farmers fora. The farmers fora were formed in parishes, with replication at the sub-county (most dominant), the district headquarters, and up to national levels to push for the interests of the farmers (Kwapong, 2015; MAAIF, 2016). The village groups would select three enterprises, which would then be harmonized with those from other villages at the parish forum, before onward submission to the sub-county for vetting and financing. The group's membership remained vibrant to a greater extent due to the social relationship that existed among the members of the community.

However, the farmers in the fora did not have adequate knowledge and experience to demand the kind of advisory services they wanted, even when the implementation guidelines mandated them to do so (MAAIF, 2016). Whereas farmers were also expected to participate in the selection of service providers and hold them accountable through the farmers fora they could not determine the kind of service providers to undertake the advisory services for them. The guidelines for the selection of members of the farmers fora did not emphasize levels of education of farmers to source competencies. Applicants for advisory service provision contracts sometimes falsified documents submitted and the NAADS selection committee comprising of farmer forum representatives and technical persons at the sub-county would not be able to verify them (Barungi *et al.,* 2016). This could result in awarding contracts to non-qualified persons in addition to many other corruption-related challenges (Feder *et al*., 2010; Kwapong, 2015). The farmer institution was therefore administratively weak and not prepared to perform the duties expected in the NAADS design (MAAIF, 2016).

The NAADS structure, which was well remunerated, compared to the Unified Extension Services (UES) in the traditional extension system, created a parallel extension system reporting to the NAADS Secretariat, as the UES reported to MAAIF. The parallel institutional reporting was an obstacle in the distribution of inputs to the farmers since accountability of performances was dominated by counter-accusations. During the FGD in the Nakaseke sub-county, farmers recalled that they were listening to NAADS officials more than the traditional extension workers because the NAADs officials would come to them frequently (because they had motorcycles) and also would bring inputs compared to the traditional staff who had nothing to give. This means that concerns from the farmers were flowing more on the NAADS reporting line and yet that line did not have the mandate to develop policies to address the concerns of the farmers, creating an institutional mischief.

Financial institutional set up for inputs and advisory services under the NAADS. According to the NAADS implementation guidelines (2001), an estimated 72% of the funds was earmarked for advisory services while inputs would take on average 7% of the entire budget (Fig 4). This provision in the guidelines was adhered to for roughly the first three years of the program (2001-2003). However, as implementation progressed between 2004-2006, farmers reasoned that advisory services could not be done without accompanied inputs. As one of the KIs argued:

"NAADS was seen as not visible and stakeholders wanted visibility that could only be achieved through inputs causing alterations of approach. The budget gradually changed from advisory services line to input provision lines without any adjustment in the guidelines or NAADS Act of 2001" (KIIs, April 2019).

Therefore, from 2004 onwards, there was a gradual increase in funding towards inputs distribution than advisory services as observed in the Nakaseke District Local Government (Figure 4).

According to Birungi *et al*. (2016), NAADS deviated from its original design of providing advisory services to inputs supply. However, even when stakeholders were in support for the farmers to instead access inputs, the findings indicated that the shift to inputs supply had little contributions to farmers' adoption and subsequent improvements of income. Most of the inputs distributed were of low quality coupled with inadequate knowledge by farmers themselves to utilize the available inputs (World Bank, 2016). During FGDs meeting in Nakaseke sub-county, farmers agreed that:

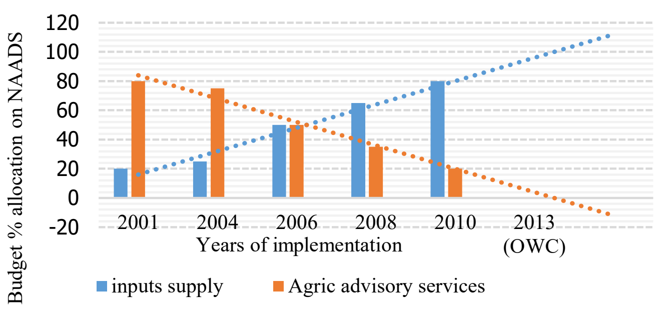
"Most of the inputs especially animals continue to be of low quality than the ones we have either kept at home or prefer. The previous animals received were so wild and uncontrollable and

sometimes we don't bother to adopt them". These discussions could also point to the understanding that the need and/or the quality of inputs received were not necessarily the only justifications for the failure of the NAADS program but also the attitude of the stakeholders within the State and non-State coalitions. Although the above trend was inconsistent with the provision of the NAADS Act 2001, the Ministry (MAAIF) responsible could not do its amendment due to their earlier negative perception towards the program. First, they looked at the Act as taking over their mandate of extension services and secondly, NAADS was pulling away a lot of resources from other programs within the ministry's activities. NAADS therefore ran with limited support of the technocrats from MAAIF and it lacked the technical staff in its establishment to specifically undertake inspection and quality assurance that remained under the Ministry's domicile

With limited support from the mother Ministry responsible for the formulation of the institutional frameworks, NAADS operated with a weak framework that could not easily be amended even when glaring gaps were detected. The implementation of NAADS was meant to be done alongside the other pillars of PMA, however, those pillars were not operationalized, a situation which overloaded NAADS in an attempt to cover the gaps (MAAIF, 2016). Spreading the resources, meant underfunding the original core areas of NAADS, among others, shifting resources to inputs distributions as demanded by the farmers and was seen as support to the visibility of the extension services. NAADS began to operate outside the legal framework that established it in 2001 on top of the many reported cases of corruption associated with procurement of inputs, low capacity of the farmers to demand extension services, and lack of technical capacity in the private sector to provide a critical mass of advisory service providers to smallholder farmers. The President of the Republic of Uganda subsequently suspended NAADS in 2013. The President later established what he called Operation Wealth Creation to undertake the input distribution activities previously done by NAADS.

As indicated in Figure 4, resources for advisory services kept on dwindling while that of inputs delivery kept on increasing over the years of implementation without any amendments in the implementation guidelines or NAADS Act 2001.When policy actors were asked what could have caused this shift, the following themes and responses were generated:

Particular	Estimated cost (million $)	%
Advisory and information services to farmers	77,425.29	71.7
Technology and Market development	7,027.35	6.7
Regulations and Technical auditing of service providers	1,475.49	1.4
Private Sector Institutional development	3,748.48	3.5
Program Management and Monitoring	18,262.81	16.9
Total	107,941.42	100

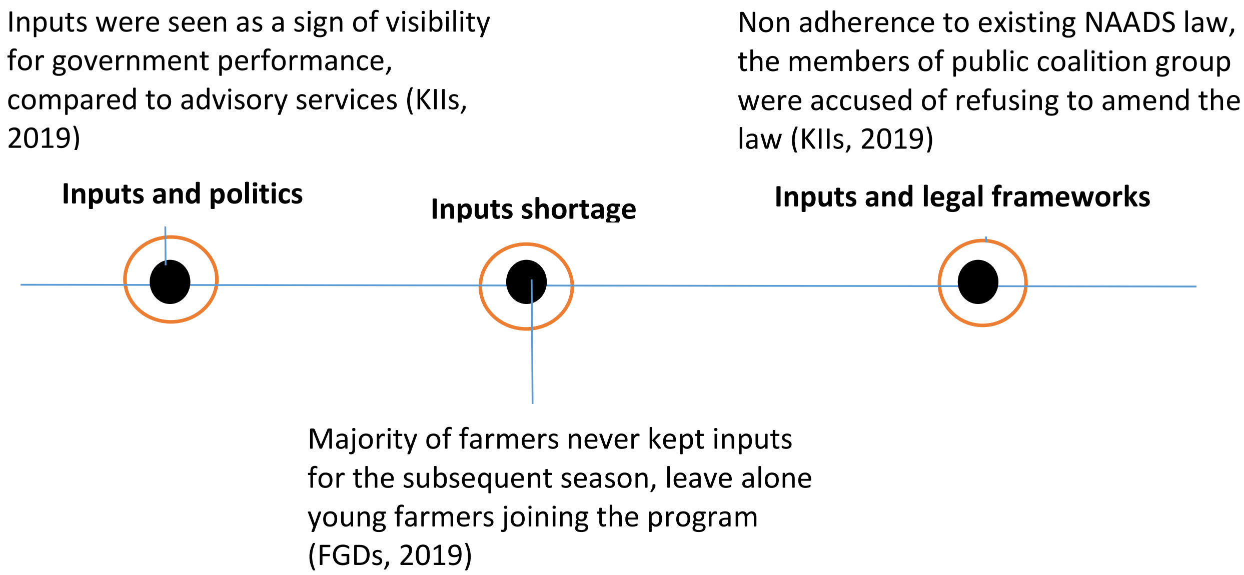


NAADS implementation guidelines 2004

NAADS implementation in Nakaseke (2004-2010)

Source: Field data

Figure 4. A Shift from advisory to input delivery roles under NAADS



According to the KIIs from a member of public sector coalition group (2019), in the early 2001, the budget for inputs was just about 20% while that for advisory services stood at around 80%. However, The NAADS budget increased exponentially and by 2010, it had reached 80% for inputs against 20% for advisory services. The focus on inputs became a priority of government even when there was no amendment on the NAADS Act to streamline inputs delivery. The counter accusations, coupled with recurrent poor quality inputs to farmers affected the performance of NAADS in the advisory services phase. The separation of advisory from inputs delivery services, again did not facilitate input access leading to frustrations by farmers, and later suspension of the approach by the President in 2013.

The Single Spine Phase (2013- Present). The Single Spine aimed at merging the parallel and separate roles of input and advisory services delivery formerly under NAADS including abolishing the unified extension approach that had persisted since 1992. Following recommendations from the Cabinet Select Committee instituted by the President, the Single Spine merged the extension services role and handed it over to the Ministry of Agriculture, Animal Industry and Fisheries while re-establishing back the extension directorate at the Ministry to oversee the roles. The input delivery role on the other hand was handed over to NAADS Secretariat, a much linear structure than the original NAADS since the extension staff under NAADS were already abolished, and a visible staff vacuum in the delivery of inputs to farmers was witnessed. The separation of input and advisory services roles became even more prominent in the single spine phase.

In July 2013, the President visited Luwero/ Rwenzori region and while interacting with the bush war veterans, there was wide spread complain that NAADS never gave them inputs and yet they (veterans) did a lot to usher in the Government into power.

In July 2013, the President launched an initiative to support civilian veterans codenamed 'Luwero–Rwenzori Anti-Poverty Campaign'. Among the thematic areas emphasized were the distributions of seeds, planting and breeding materials (MAAIF, 2016). The MAAIF, NAADS and Coffee Development Authority (CDA) participated in the initiative under the coordination of the Office of the Prime Minister (OPM). The targeted priority commodities were coffee, tea, citrus, mango, maize, beans

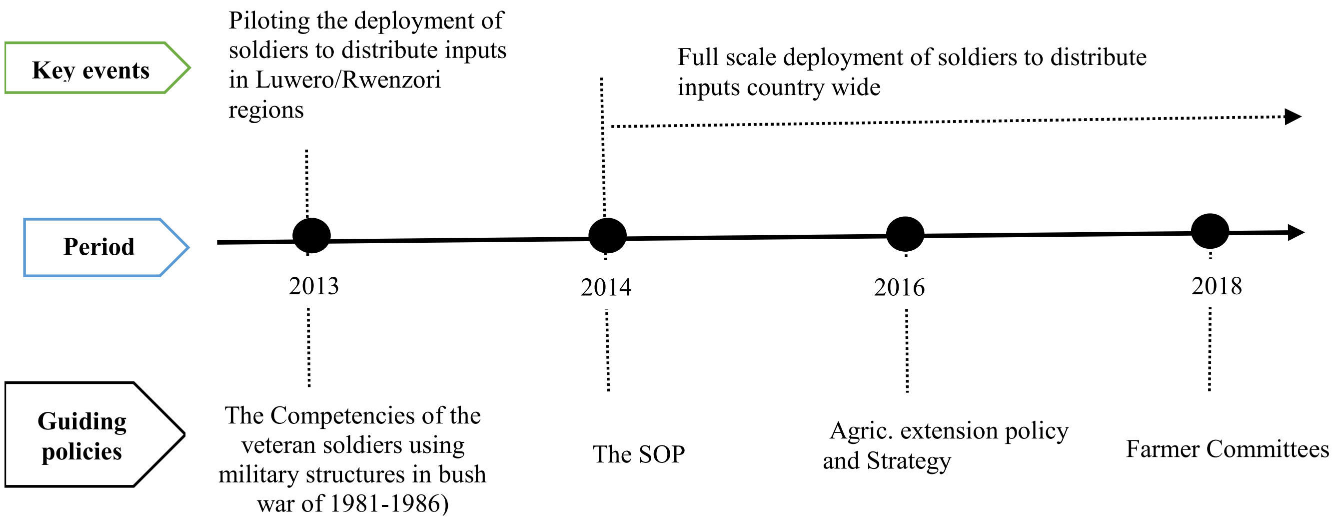


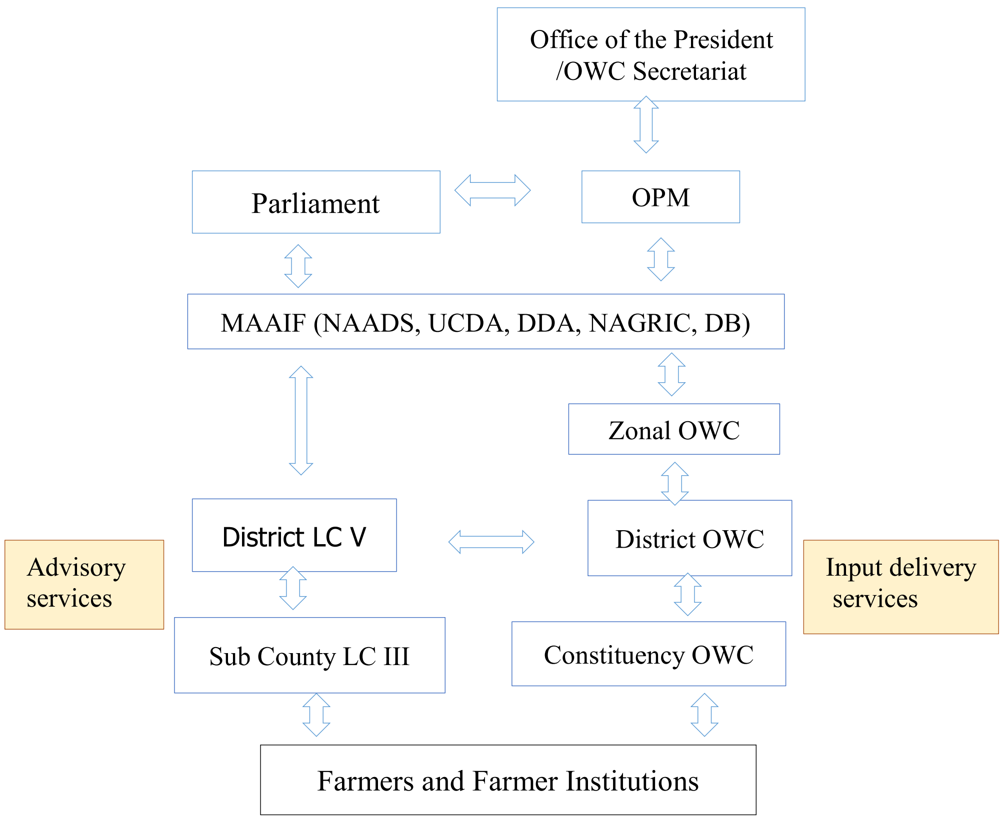
Figure 5. Key institutional developments in the single spine phase

and cassava covering districts of Nakaseke, Wakiso, Luwero, Kiboga, Mityana, Kibaale, Mukono, Kiruhura, Isingoro, Mayuge, Manafa, Gulu, Amuru, Bundibugyo, Ntoroko, Kabarole, Kyenjojo, Buhwezi, Butambala, Gomba, Mpigi and Lwengo. Mobilization in the units was launched by the President from Ngoma sub-county in Kabalega unit which eventually spread to all other units. The implementation of the initiative was a collaborative effort of the UPDF commanders (soliders) who took the coordinating roles and the designated Local governments who carried out the mobilization and quality assurance roles (MAAIF, 2016). The report captured in the NAADs Monitoring and Evaluation Framework of 2016, and alluded to by the report of the Parliamentary Committee on Agriculture in 2017, indicated that the Luweero-Rwenzori initiative was largely successful. The President then ordered a large scale deployment of the soldiers covering the whole country on the 9th June 2014, during the Hero's day celebration in Mityana District (Parliament of Uganda, 2017).

The OWC journey begun in July 2013, when the Uganda President was on a tour in Nakaseke district and had interactions with the veterans of the NRA war, who intimated that they were unable to benefit from programs being delivered by the government they ushered into power. This was on the account that the NRA war that brought the current government into power had its bases in Luwero/Rwenzori regions. In particular, the veterans argued that NAADS program was unsuccessful in delivering inputs to the beneficiaries. The President reportedly fronted the idea of using the veterans themselves to pilot the distribution of inputs to the community in the war districts of Luwero and Nakaseke. The Pilot was conducted in veterans' units (Kabalega, Luta, BB Mondrana, Ngoma, among others) established during the NRA war and run by military principles (KIIs, 2019)

According to OPM (2015) assessment report, the veteran soldiers successfully executed their roles in delivering inputs to farmers and there was reported increase in production and yields of maize in the region. Consequently, in 2014, the President ordered massive deployment of soldiers to spearhead input delivery in all the other districts in the country. In the same year (2014), a Cabinet Committee was constituted by the President to draft an institutional framework for guiding the operations of soldiers. This committee delivered the Standing Orders of Procedures (SOP), a framework that has been used to man Operation Wealth Creation Program to date (Birungi *et al*., 2016; MAAIF, 2016). The Committee made recommendations which were adopted by the Cabinet in June 2014 as follows; 1) Transfer the extension services from NAADS to MAAIF; 2) Merge the extension services (both in terms of human and financial resources) at the local government level into District Production Department to eliminate parallel extension, and 3) Separate inputs distributions from extension services delivery. Accordingly, the NAADS Secretariat was to remain lean, handle only inputs chain management and procurement of strategic inputs of public interest, and promote agribusiness technologies. MAAIF was directed to work on a document that would facilitate the involvement of the soldiers in the extension services. This process culminated in the development of the Standard Order of Procedures (SOP), Agricultural Extension Policy and Strategy of 2016.

Guided by the SOP, input delivery and advisory services were more strongly separated with soldiers leading input delivery while extension workers remained with the advisory roles.



Source. Page 6 of SOP manual

Fig. 6. Inputs and Advisory services institutional path ways in OWC Program

Governance structures under OWC. At its topmost organ, OWC is headed by Inter-Ministerial Committee chaired by Minister for the Presidency and comprising of Ministers responsible for Agriculture, Trade, Finance, Water & Environment and Local Government. The Secretariat is coordinated by the senior Presidential advisor on defence and security, working with directors responsible for inputs, low-cost housing, value addition, pension, among others. They coordinate activities such as planning, supervision and evaluation of the progress of the OWC program. Next in the hierarchy are the Zonal OWC coordinators or commanders operating in the 18 agricultural zones in the country. These zones include Acholi, Ankole, Bugishu, Bukedi, Bunyoro, Busoga, Kampala, Karamoja, Kigezi, Lango, Madi, Masaka, Mengo, Mubende, Rwenzori, Sebei, Teso and West Nile. The zonal coordinators oversee the activities of district and constituency coordinators who, together with the local government and community leaders identify relevant enterprises at the household level and coordinate with line agencies or departments to ensure socio-economic transformation. Also OWC provides a link with relevant ministries, agencies or departments directly linked to the agricultural production chain such as the National Agricultural Research Organisation (NARO), Uganda Industrial Research Institute, Financial institutions, Cotton Development Organisation (CDO), NAADS, National Forestry Authority (NFA), Uganda National Roads Authority (UNRA), Makerere University and UPDF. According to the SOP, OWC is supposed to work hand in hand with the production departments in the local governments.

The organogram shows two reporting lines (A and B), each with specific roles. Reporting line A alludes to the traditional system where advisory services to the farmers and other implementation issues go from farmers through the sub-county leadership to the district. The district reports are then submitted to the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) for appropriate responses. Parallel to this is reporting line B where the OWC commanders report to their own commanders and directly to the office of the President. This pathway deals majorly with input delivery processes. However, both pathways generated and propagated the double and parallel reporting challenges in the inputs' distribution, an inherent problem documented in the previous phases.

In an attempt to mitigate the gap created by the absence of farmers groups, field findings confirmed that OWC began instituting back farmers' institutions in 2018 but was renamed as farmers' committees. The committee comprises farmer representatives of the different enterprises at parish levels. The roles of the farmers' committee are widened beyond OWC to include sensitization of farmers on OWC and other programs, coordinating with other organizations involved in farming, prioritizing the needs of farmers among others. According to farmers (KIs), giving them wider responsibilities does not restrict them to be answerable to OWC alone, which affects their commitment towards OWC program

Financial institutions under the OWC program. At the local government level, the SOP would require the constituency OWC commanders at the district to report to the District Production Officer (DPO) who is the head of agricultural extension services at the local government. It is established that this institutional requirement has been flouted, especially where the resources to facilitate the OWC commanders do not pass through the Production and Marketing Grants (PMG) under the leadership of the district authorities. This is further contrary to the requirement that all resources for extension services in the district be harmonized under the single spine extension reforms approved by the Cabinet in 2014 (MAAIF, 2016). As such OWC program resources operating outside the arms of the DPO compromise the decentralized functions of agricultural extension services. This, as further indicated in the report by the Parliamentary Committee on Agriculture (Parliament of Uganda, 2017) continues to affect extension services in the local governments since there is no harmony between the traditional extension workers and the well-remunerated OWC commanders.

The influence of the institutional reforms towards OWC Program. During the Regulatory phase, the colonial leaders used instructors and chiefs to deliver inputs to farmers. The chiefs applied coercion as a tool for enforcing orders over farmers to grow cash crops that provided raw materials for their industries in Britain. In the absence of any appropriate legal frameworks to guide inputs and advisory services, coercion in itself became a tool for enforcing compliance and achieving outputs. In the civil-military theory (Gallie, 2008) and further as argued by Morrish Zanowitch in his book of the professional soldier, soldiers are well known to apply coercion as an immediate tool to subdue its enemies to divulge information that helps in their success in the battle fields. Involvement of soldiers using a similar approach as the chiefs did, would therefore be perceived not only as a normal intervention but an extension of an earlier approach in the extension services delivery in the country. In one of the KIIs of 2019, the soldier alluded to the above arguments that;

"the concepts behind our deployment under OWC program were hatched in the military units maned by the veteran soldiers of the bush war that ushered the NRM government to power and has been carried along the entire input delivery pathways over the years".

Farmers agreed to this and explained that once inputs are received by household, the soldiers would ensure that the inputs are correctly used as directed and sometimes would coerce farmers to utilise the inputs as agreed.

During the educative phase, the capacities of extension workers were built to be able to offer all round extension services package to farmers in the different sub sectors of production. For example, during the introduction of the Unified Extension Approach around 1992, each extension worker was required to possess knowledge in the different sub sectors of crops, livestock, fisheries and entomology even when their professional carrier did not support such a broad assignment. Short courses in integrated extension services were conducted though with minimal success as majority of extension workers chose to tore their specific profession in the extension services delivery. By implication, introducing soldiers without any appropriate trainings in extension services would not be an exceptional intervention as long as short trainings could be offered to them as was the case with extension workers in the educative phase.

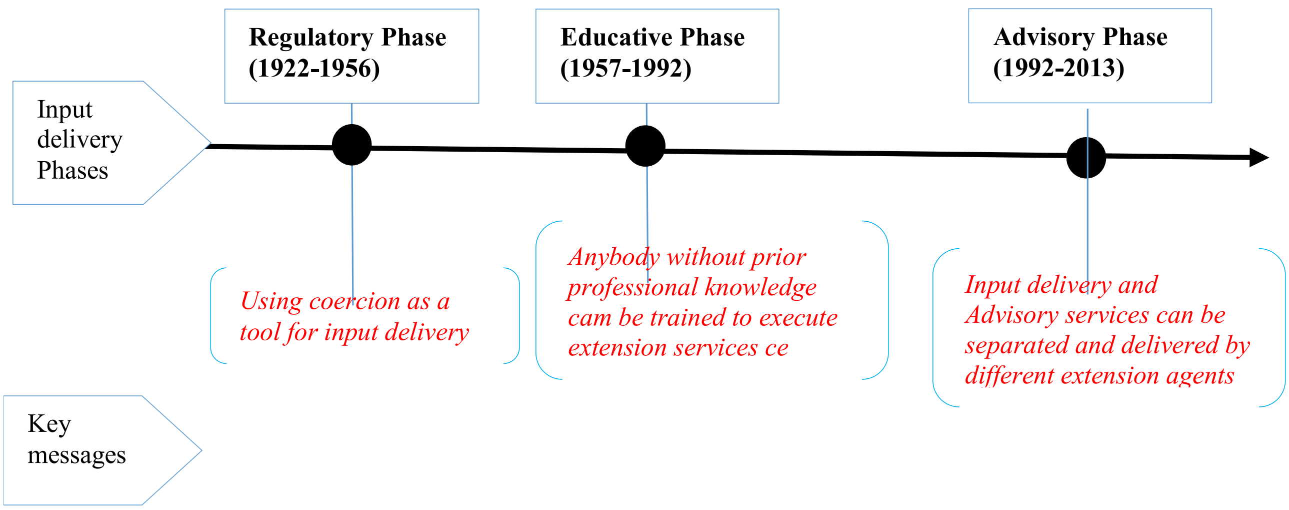


Figure 6. Evolution towards OWC Program

In the Advisory Services phase, the NAADS Act of 2001 introduced the separation of inputs from advisory services delivery to farmers. Initially, NAADS had allocated more resources to advisory services compared to input services in its implementation guidelines. However, farmers realised that advisory services alone were insufficient to improve their household production and productivity unless combined with inputs supply. Whereas farmers wanted inputs to support their knowledge obtained from heavy investments in advisory services over the years, politicians believed that trainings and other advisory services were not as tangible as inputs supply and therefore would undermine accountability of government to the public. More pressure was therefore piled on NAADS by farmers themselves and politicians to prioritise inputs supply over advisory. So, as implementation progressed, there was more resources diverted to input supply than advisory services delivery. By the time the President suspended NAADS including all its staff in 2013, inputs supply was dominant. And, in the absence of extension workers, soldiers were deployed to fill the gap to continue with input distribution, a process that led to evolution of the OWC program to farmers.

CONCLUSIONS

Agricultural Inputs distribution in Uganda has gone through decades of reforms as government and stakeholders push for better alternative approaches to meet farmers' needs. Most of the reforms were championed not by the government and beneficiary farmers but by donors who had the resources to finance the reforms. Government and farmers, therefore, remained on the receiving end with minimal conceptualization of these reforms. Deep in the centre of these reforms was the question of whether inputs and advisory services could be separated or fused and delivered as a package to farmers.

Separating or fusing inputs and advisory services to farmers did not yield any reasonable success in delivery of inputs to farmers for improved production and productivity. Therefore, it is practically impossible to separate inputs supply from advisory services if effective agricultural transformation is to be achieved in farmers' households. Farmers experiences have proved that advisory and input delivery services are complementary functions, none of which would succeed in the absence of the other.

The above notwithstanding, one of the critical factors that negatively influenced the levels of success of the reforms was the weak capacity of the farmers to not only understand what was being prepared for them but also inadequate ownership of the different interventions in the inputs distribution chain.

Whereas the Government embraced the different institutional frameworks to facilitate inputs distribution in the country, harmonization of the different frameworks could not be fully achieved. Several parallel institutional mandates continued to compete with each other for farmers' attention. For example, the NAADS program runs a completely different structure from the traditional unified and single spine extension services as earlier agreed by the same Government. This means that the little resources for inputs distribution got scattered leading to obvious wastage in the distribution chain. A similar parallel structure has persisted under the current OWC program in which the soldiers have their channel of communication while the approved single spine system has its reporting structure.

IMPLICATIONS FOR POLICY AND PRACTICE

Implications for policymakers. The study on the institutional reforms towards OWC program is contributing to the ongoing struggles and debate among developing countries on how best to deliver extension services to smallholder farmers. Involving the soldiers in inputs distribution is viewed as part of the pluralistic approach in extension reforms being encouraged in Uganda, just as was the successful case in Indonesia. However, the involvement of the soldiers in inputs distribution in Uganda is being constrained because the program is not properly anchored on any legislative instrument that can facilitate OWC to access resources directly from the government-consolidated fund. As the program continues to access funds through the NAADS Secretariat, it is unable to properly articulate its work plans and budgets before parliament. Development practitioners should therefore reformulate the OWC program by amending the NAADS Act of 2001 to provide for inputs distributions as well as anchoring its input delivery role in the general institutional frameworks for extension services.

Implications for practitioners. The reporting procedures between the OWC Secretariat, NAADS and MAAIF require urgent harmonization. It was established that the soldiers report directly to OWC headquarters and finally to the Office of the President while the agricultural extension workers are reporting to MAAIF, within the same program. Stakeholders recommended that the reports be finalized at the district headquarters and forwarded by the chief administrative officer to all other stakeholders through a central information management system.

ACKNOWLEDGEMENTS

The work was supported by the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), with funding from the Carnegie Corporation of New York. We thank the Uganda National Council of Science and Technology and the office of the President of the Republic of Uganda for granting permission to conduct this study. Furthermore, we are grateful to the respondents from Kapeka and Nakaseke sub-counties, Nakaseke District, Ministry of Agriculture, Animal Industries and Fisheries, National Agricultural Advisory Services, Operation Wealth Creation and Association of Forum for Agricultural Extension Services in Uganda who provided information for this study.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Ajzen, I. 1985. From intentions to actions: A theory of planned behavior. pp.11-39. In: Action Control. Springer, Berlin, Heidelberg.

Barungi, M., Guloba, M. and Adong, A. 2016. Uganda’s agricultural extension systems: how appropriate is the single spine structure. Economic Policy Research Center, Kampala, Uganda.

Benin, S., Nkonya, E., Okecho, G., Randriamamonjy, J., Kato, E., Lubade, G. and Kyotalimye, M. 2011. Returns to spending on agricultural extension: The case of the National Agricultural Advisory Services (NAADS) program of Uganda. *Agricultural Economics* 42 (2): 249–267

Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., Mbabu, A., Spielman, D. J., Horna, D., Benin, S. and Cohen, M. 2009. From Best Practice to Best Fit: A framework for designing and analyzing pluralistic agricultural advisory services worldwide. *The Journal of Agricultural Education and Extension* 15(4): 341–355.

Food and Agricultural Organisation (FAO). 2008. Global Review of Good Agricultural Extension and Advisory Service Practices. FAO, Rome.

Food and Agricultural Organisation (FAO). 2015. Is aid to agricultural innovation a priority for the international community? FAO, Rome.

Feder, G., Willet, A. and Zijp, W. 1999. Agricultural extension generic challenges and some ingredients for solutions. The World Bank Policy Research Working Paper 2129. Washington DC: The World Bank.

Dalsgaard, J. P. T., Minh, T. T., Giang, V. N. and Riise, J. C. 2005. Introducing a Farmers'

Livestock School Training Approach into the National Extension System in Vietnam. Overseas Development Institute (ODI).

Afranaa Kwapong, N. and Nkonya, E. 2015. Agricultural extension reforms and development in Uganda. *Journal of Agricultural Extension and Rural Development* 7 (4): 122-134.

Nederlof, E. S., Wennink, B. and Heemskerk, W. 2011. Access to agricultural services Background Paper for the IFAD Rural Poverty Report 2011.

Parliament of Uganda. 2017. MAAIF-17-Report-on-the-implementation-of-the-Operation-Wealth-Creation-programme-in-Uganda.pdf.

Platteau, J. P. 2004. Monitoring elite capture in community-driven development. *Development and Change* 35 (2): 223-246.

Rivera, W. M. and Qamar, M. K. 2003. Agricultural extension, rural development and the food security challenge. Rome: Food and Agriculture Organization of the United Nations.

Rwamigisa, P. B., Birner, R., Mangheni, M. N. and Semana, A. 2018. How to promote institutional reforms in the agricultural sector? A case study of Uganda's National Agricultural Advisory Services (NAADS). *Development Policy Review* 36 (5): 607-627.

Ministry of Agriculture, Animal Industries and Fisheries (MAAIF). 2013. National Agricultural Policy. September 2013, Entebbe, Uganda.

Ministry of Agriculture, Animal Industry and Fisheries (MAAIF). 2016. The National Agricultural Extension Strategy (2016/17-2020/21) October 2016, Entebbe, Uganda

Ministry of Defense and Veteran Affairs (MoD). 2014. The Standard Order of Procedure for Operation Wealth Creation, Kampala Uganda.

Ministry of Public Service. 1998. Post Constitutional Restructuring of the Ministry of Agriculture, Animal Industry and Fisheries. Final Report, May 1998, Kampala, Uganda.

Plan for Modernisation of Agriculture (PMA). 2000. Eradicating Poverty in Uganda: Government Strategy and Operational Framework. Ministries of Agriculture, Animal Industry and Fisheries, and Finance Planning and Economic Development, Kampala, August 2000.

Poverty Eradication Action Plan (PEAP). 2004. Poverty Eradication Action Plan: Draft for Stakeholder Workshop. Ministry of Finance Planning and Economic Development, Kampala, March 2004.

Semana, A.R. 2002. Agricultural Extension Services at Crossroads: Present Dilemma and Possible Solutions for Future in Uganda. Department of Agricultural Extension/ Education, Makerere University. A paper presented at the Codesria-IFS Sustainable Agriculture Initiative Workshop, Kampala, Uganda. December 15th-16th 2002. (Unpublished).

Uganda Bureau of Statistics (UBOS). 2010. Uganda Census of Agriculture 2008/2009. Volume III: Agricultural household and Holding Characteristics Report, December 2010, Government of Uganda, Kampala, Uganda.

Uganda Bureau of Statistics (UBOS). 2012. National Statistical Report, Government of Uganda, Kampala, Uganda.

United States Agency for International Development (USAID). 2015. An Evaluation of the Rural Advisory Services Program (RASP) and Related Activities Under Feed The Future. USAID.

World Bank. 2016. Uganda Poverty Assessment Report. Farms, cities and good fortune: Assessing poverty reduction in Uganda from 2006 to 2010. World Bank.

African Journal of Rural Development, Vol. 7 (1): January-April 2022: pp. 20-37. ISSN 2415-2838

Influence of land tenure security on household food security among small holder farmers in Narok County, Kenya

J. J. MBUDZYA,* E. O. GIDO. and G. OWUOR
Department of Agricultural Economics and Agribusiness Management, Egerton University, P.O.Box 536-20115, Egerton, Kenya
*C**orresponding Author:** jabujoseph@gmail.com

ABSTRACT

A secure tenure over agricultural land is crucial in efforts aimed at improving the livelihoods of rural people. However, empirical studies to validate this statement are still limited especially in Sub Saharan Africa. This study analysed the influence of land tenure security on household food security among small holder farmers in Narok County, Kenya. The study used cross-sectional data collected from 366 small holder farmers obtained from a multistage sampling procedure. Endogenous switching regression (ESR) model was used to obtain econometric results for this study. Household food security was measured by food consumption scores and the ESR model results show that, household food security status was influenced by marital status, education level and age of the household head as well as household size, household income, maize productivity, number of contacts with extension agent, access to credit, and ownership of an ox. Land tenure insecure households would increase their food security by 38% if they were land tenure secure while land tenure secure households would have decreased food security status by 4% if they were land tenure insecure. Therefore, land tenure security increased household food security. The findings call for enactment of policies and strategies that would facilitate access to secure ownership and transfer land rights by rural farming households thereby encouraging farm investments for improvement of household food security.

Key words: Endogeneity, endogenous switching, food consumption score, Kenya, land rights, land tenure security, self-selection

RÉSUMÉ

Une tenure foncière sécurisée sur les terres agricoles est cruciale dans les efforts visant à améliorer les moyens de subsistance des populations rurales. Cependant, les études empiriques pour valider cette affirmation sont encore limitées, en particulier en Afrique subsaharienne. Cette étude a analysé l'influence de la sécurité de la tenure foncière sur la sécurité alimentaire des ménages parmi les petits agriculteurs du comté de Narok, au Kenya. L'étude a utilisé des données transversales collectées auprès de 366 petits agriculteurs obtenues à partir d'une procédure d'échantillonnage à plusieurs niveaux. Le modèle de régression à commutation endogène (ESR) a été utilisé pour obtenir les résultats économétriques de cette étude. La sécurité alimentaire des ménages a été mesurée par des scores de consommation alimentaire et les résultats du modèle ESR montrent que l'état de sécurité alimentaire des ménages était influencé par l'état civil, le niveau d'éducation et l'âge du chef de ménage, ainsi que la taille du ménage, le revenu du ménage, la productivité

Cite as: Mbudzya, J.J., Gido, E.O. and Owuor, G. 2022. Influence of land tenure security on household food security among small holder farmers in Narok County, Kenya. *African Journal of Rural Development* 7 (1): 20-37.

Received: 29 January 2021
Accepted: 28 November 2021
Published: 30 April 2022

du maïs, le nombre de contacts avec un agent de vulgarisation, l'accès au crédit et la propriété d'un bœuf. Les ménages dont la tenure foncière était incertaine augmenteraient leur sécurité alimentaire de 38% s'ils avaient une tenure foncière sécurisée, tandis que les ménages dont la tenure foncière était sécurisée verraient leur état de sécurité alimentaire diminuer de 4% s'ils avaient une tenure foncière incertaine. Par conséquent, la sécurité de la tenure foncière augmentait la sécurité alimentaire des ménages. Les résultats appellent à l'adoption de politiques et de stratégies facilitant l'accès à la propriété sécurisée et au transfert des droits fonciers par les ménages agricoles ruraux, encourageant ainsi les investissements agricoles pour améliorer la sécurité alimentaire des ménages.

Mots clés : Endogénéité, commutation endogène, score de consommation alimentaire, Kenya, droits fonciers, sécurité de la tenure foncière, auto-sélection

INTRODUCTION

Globally, food insecurity has been a major challenge and policy issue. Majority of the policies in the developing countries have been aimed at improving agricultural productivity to ensuring food security. Out of the 768 million people who are food insecure globally, about 600 million are found in Africa, Asia and Latin America (FAO *et al.,* 2022). Additionally, close to 600 million people are projected to be food insecure by 2030 (Lawry *et al.,* 2017). This underscore the challenge of achieving the Sustainable Development Goals (SDG) number two of achieving zero hunger by 2030. It is estimated that more than 1.1 million people in Kenya are in acute food insecurity crisis stage and the number is expected to rise up to 3.5 million in the next half of 2022 (WFP, 2022). The world population is projected to be at 9.3 billion mark by 2030, therefore the world's food production must increase by approximately 70% in order to meet the growing food demand (FAO *et al.,* 2021). According to Lawry *et al*. (2017), land tenure insecurity is identified as one of the major causes of food insecurity since majority of the resource poor small-holder farmers are the main food producers in third world countries such as Kenya. The study defines small holder farmer as one who farms on less than 5 hectares of land.

Land tenure security and food security have conventionally been viewed as distinct subjects. This is because land tenure security is primarily seen as using legal and institutional angle while food security is explained using economic, social and bio-medical terminologies (Maxwelll and Wiebe, 1999). In addition, research on land tenure security especially in developing countries is faced with variations and complexities associated with land tenure systems (Holden and Ghebru, 2016). The policy significance of the linkage between land tenure security and food security is further emphasized by the increasing land scarcity especially in poor countries who face climate related risks (Godfray *et al.,* 2010; Holden and Otsuka, 2014). However, their definitions indicate close conceptual linkages. Land tenure security occurs when someone has unlimited rights of access to and use of land due to social, legal systems, and governing institutions (Holden and Ghebru, 2016). Food security on the hand is defined as "a situation when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life" (FAO, 1996). Therefore, in conceptual terms, the contribution of land tenure security on food security occurs when people have secure access to land and related resources such as forests, rivers, and lakes. The resources would enable them to produce enough food for their own consumption or sale to get income that could be used to buy food. The linkage can also be manifested by the relationship between land tenure security, resource use, agricultural productivity, and income generation (Ghebru and Holden, 2013; Mendola and Simtowe, 2015; Lovo, 2016).

Land tenure security is key in the achievement of poverty reduction, food, and nutritional security for rural households whose livelihood depends on agriculture (Higgins *et al.,* 2018). Similar findings by Espinosa (2019) indicates that there is a 3.2% significant increase in food availability for families with secure land tenure than those with insecure land tenure. Land tenure security reduces incidences of land disputes, promotes use of land as a collateral for credit facilities, and encourages both short term and long term investments that would increase productivity and incomes (Linkow, 2016; Lovo, 2016). ANGOC (2017) noted that land tenure security stimulates investments in agriculture as well as reduces unfair land expropriation and forced migration thus increasing households' resilience. Ajefu and Abiona (2020) argue that food security is not only affected by climatic and weather conditions but also land tenure security. However, recent literature on the linkage between land tenure security and food security has been conflicting (Payne *et al.,* 2016). Kenny-Lazar (2016) argues that, persons with land tenure insecurity, may still be food secure if they have access to employment opportunities due to higher education levels. Research by Bamire (2010) indicates that land tenure security had no significant effect on household food security. Land titling did not have an impact on land investment (Besley, 1995; Deininger and Castagnini, 2006; Deininger and Jin, 2006). Moreda (2018) in Ethiopia suggests that, land tenure insecurity doesn't contribute to land degradation but rather limited access to other resources such finance. Other studies such as Migot-Adholla *et al*. (1994) and Pinckney and Kimuyu (1994) found no significant effect of land titling on agricultural productivity. In most developing countries, food security is associated with a particular crop.

In Kenya, maize farming plays a vital role in the overall contribution to food security. Maize (*Zea mays*) is one of the major cereal crops in the world, ranked third after rice and wheat (Mekureyaw, 2017). It is the most widely cultivated cereal grain in Africa and is considered a staple food (Nagarajan *et al*., 2019). In Kenya, it is considered as both a food security and the main staple food crop hence its inclusion in this studywas deemed necessary. Previous studies by GoK (2021) have shown that, maize productivity has been on the decline. Land tenure insecurity has been cited as one of the key contributors to conflict, low land investments, and low maize productivity (Mekureyaw, 2017). Despite the importance of land tenure security on food security as highlighted, there is limited literature on this crucial subject especially in Sub Saharan Africa. Thus, to bridge this knowledge gap, the study seeks to answer a key research question on whether land tenure security influences household food security. This is expected to provide empirical evidence on the influence of land tenure security on household food security in Narok, county, Kenya.

Conceptual framework. Conceptually, the main causes of land tenure insecurity are encroachment and grabbing of land by private investors or reallocation by government. According to Holden *et al*. (2013) land rights can be categorized into three namely; user rights, transfer rights and mortgaging rights. However, in this study, land rights are broadly grouped into two, that is user rights and transfer rights because mortgaging rights as mentioned by Holden *et al*. (2013) may involve the transfer of land rights from one party another hence can still be classified under the transfer rights. User rights include; right to choose which crop to grow, the right to do land fallowing, right to develop the land, right to dispose of crop produce after harvesting, and the right to prevent others from using such as grazing. On the other hand, transfer rights are the right to give land under customary line, right to inherit land, right to lease or rent land, right to sell the land, and the right to mortgage.

Transfer rights such as the right to rent or lease or right to sell may have restrictions and therefore affect the functionalities of land markets. Furthermore, such restrictions also affect who is allowed to produce on the land, or whether they will produce only for home consumption, for the market or both. This therefore affects the food security of both the users and owners. Additionally, it affects the supply of food in the market. In the presence of well-defined and stronger user rights, rights holders are more likely to increase their investments on the land and thereby increase productivity. Since most of the rural dwellers are small holder farmers and food is the main product producing mainly for home consumption and the remaining for the market, enhancing their rights would more likely improve their food security status. Land can also be used as a collateral to access credit facilities in financial institutions. If the credit is invested on the land, it is more likely to increase agricultural productivity and also food security. In addition, to land tenure security, household food security is affected by other socio-economic, land and institutional characteristics such as age, marital status, education level of the household head, household size, land and parcel size, land access, group membership, market access among other factors.

RESEARCH DESIGN

Study area and sampling procedure. The study was carried out on 366 randomly selected farming households in Narok county, Kenya. The county consists of six (6) sub-counties and 30 wards. According to the KNBS (2019) the county population is approximately 1,057,873 persons with a gender ratio of 1:1. Land ownership in the county is categorized into three (3); community, trust, and private land. In order to select the respondents, the study used a multistage sampling procedure. Firstly, a purposive selection of Narok county was done due to the high incidences of land tenure insecurity related conflicts (Kariuki *et al.,* 2016). Secondly, two sub counties (Transmara West and Transamara East) were chosen because of the highest reported cases of land based conflicts in the county. Thirdly, two wards were chosen in each sub county since they had the highest number of small holder farmers in the respective sub-counties (CGN, 2018). Lastly, to obtain the 366 small holder respondents, every 5th person on an alphabetically arranged list of 2000 eligible small holder farmers obtained from the county agricultural offices was chosen. The sample size per ward was based on proportionate to the size of the small holder farmers in the respective ward. Data were collected using questionnaires installed in Open Data Kit (ODK) software while data analysis were done using Stata 15 computer software (Stata Corp, 2014).

Analytical Framework

Measurement of key variables . The study used household food security as the dependent variable and land tenure security as the main independent variable. Household food consumption score (HFCS) was used to measure household food security. HFCS is a 7-day recall period method that captures the degree and frequency of consumption of 12 food groups (Kennedy *et al.,* 2010; Wekesa *et al.,* 2018). A higher score represents a higher food security status. The longer reference period allows for capturing of wide range of food groups consumed hence the best indicator of food security (Wekesa *et al.,* 2018). HFCS was used as a continuous variable. Food security can be analysed at different levels such as individual, household or regional. This study used the household level since it is the institution used by most rural dwellers to gain access to both food and other resources such as land. In addition, the household head is likely to be a key decision maker on matters production, consumption and investment as suggested by Mallick and Rafi (2010), Kassie *et al*. (2014) and Tibesigwa and Visser (2016).

In order to measure land tenure security, the study employed a composite measure consisting of various rights over the land. Security of land tenure can be assessed using three dimensions: user rights, transfer rights, and the autonomy given to the holders of rights, specifically the transfer rights (Brasselle *et al.,* 2002). In achieving this purpose, the study used ten indicators of land rights categorized into two broad categories (right to use and right to transfer) (Table 1). The study adopted Brasselle *et al*. (2002) approach that appreciates the different weights each right possesses as opposed to assigning equal weight to all the rights as suggested by Place (2009). In this approach, respondents were asked whether they had a permanent, transitory (temporary), or none of the user rights while on transfer rights, they were asked whether, they required approval from someone else or not.

The indicators of land user rights are as follows; (i) choice of crop to grow, (ii) land fallowing and cultivation at the end of fallow period, (iii) make land developments, (iv) dispose of crop produce, and (v) prevent people's livestock from grazing on the land. On land transfer rights, respondents were asked if they required any approval from someone else to enjoy the following indicators of rights of land transfer (vi) give land along customary lines, (vii) transfer land as an inheritance, (viii) lease land in exchange for cash, (x) sell land, and (xi) mortgage the land. All the indicators of user and transfer rights were measured as dummy variables. These rights capture the existing concerns relating to land tenure security that may affect investment.

Table 1 presents the frequency distribution results of the various land rights (to use and transfer) held by the respondents in the study area. Among the sampled households, choice of crops to grow (97.81%), land development (91.80%), and the right to prevent grazing (92.62%) were the most common rights, hence could not to be used in categorization. On the other hand, prevalent transfer rights were inheritance right (77.87%), followed by right to lease land (68.85%), right to give land along customary lines (65.03%), right to sell the land (60.38%), and lastly right to mortgage (60.65%). Thus only two user rights; right to land fallowing (81.97%) and right to dispose of crop produce after harvesting (86.34%), in addition all the transfer rights were used to create categories since they exhibited sufficient variations.

Table 1. Frequency distribution table of sampled households based on possession of the various land rights

Type right	%	Type of right	%
(i) Choice of crop to grow		(vi) Give land also customary line	
No right	2.19	No right	34.97
Temporary right	14.75	Without Approval	39.07
Permanent right	83.06	With Approval	25.96
(ii) Land fallowing		(vii) Inherit land	
No right	18.03	No right	22.13
Temporary right	13.39	Without Approval	51.09
Permanent right	68.58	With Approval	26.78
(iii) Land development		(viii) Rent or lease land	
No right	8.20	No right	31.15
Temporary right	17.21	Without Approval	40.98
Permanent right	74.59	With Approval	27.87
(iv) Dispose of crop produce		(ix) Sell land	
No right	13.66	No right	39.62
Temporary right	12.84	Without Approval	31.69
Permanent right	73.50	With Approval	28.69
(v) Prevent grazing		(x) Mortgage land	
No right	7.38	No right	39.35
Temporary right	12.84	Without Approval	28.96
Permanent right	79.78	With Approval	31.69
Total	100.00	(366 households)	100.00

To differentiate between secure and insecure land tenure households, two (2) categories, secure land tenure and insecure land tenure were derived from the data hence making the land tenure security (LTS) a binary variable. Category 1 (land tenure insecure) if they do not hold any transfer rights or only hold right inherit and right to give land along traditional lines or one of the two rights and don't hold more than two user rights (whether permanent or transitory) or do not hold the latter two rights (or one of them) or have at least two permanent or transitory user rights in addition to rights (i), (iii) and (v). Category 2 (land tenure secure) if apart from the rights to inherit and to give land along customary line, they hold rights to rent or lease land, to sell land, to mortgage land (with or without approval), and at least two permanent rights of use in addition to rights (i), (iii) and (v). This approach allows for capturing of the different roles of land tenure security alternatives for rural dwellers (Brasselle *et al.,* 2002).

Model Specification

The study used endogenous switching regression (ESR) to analyse the influence of land tenure security on household food security. The endogenous switching probit regression method was modelled in two stages as illustrated by Di Falco *et al*. (2011). Stage one involved analysing the determinants of land tenure security. In this stage, a probit model was used since land tenure security was measured as a binary variable (secure land tenure =1 and insecure land tenure= 0). Stage two was the analysis of the effect of land tenure security on food security estimated separately for both households with secure land tenure and those with insecure land tenure. The effect of land tenure security on food security was modelled following the utility maximization approach. In the approach, it was assumed the following; U_{i1}^* represents the latent variable of the expected utility that i^{th} household derives by having secure land tenure compared to one who has insecure land tenure U_{i0}^*. Household land tenure security occurs if net benefits outweighs the net costs, that is $C_i^* = U_{i1}^* - U_{01}^* > 0$. C_i^* is a function of latent variables determined by socio-economic, land related, and institutional characteristics and the residual term as represented in equation 1.

$$C_i^* = X_i^* \beta + \mu_i .. \quad (1)$$

$$\begin{bmatrix} C_i = 1 \; if \; C_i^* > 0 \\ \quad = 0 \; if \; C_i^* \leq 0 \end{bmatrix} \quad (2)$$

where C is a binary variable which takes a value of 1 if the household is land tenure secure and 0 if the household is land tenure insecure. β is a vector of unknown parameters to be estimated in the model while X is a vector of explanatory variables and μ represents error term with a mean of 0 and variance of δ^2. Since land tenure security affects household food security, let the household food security be *(Y)* which is a function of other factors, J_i is the vector of the exogenous variables. Equation 2 presents the criterion of a household being land tenure secure or otherwise. In the ESR, the study used two separate models (regimes) for those with secure and insecure land tenure as expressed in equations 3 and 4.

$$Y_{1i} = \alpha_1 J_{1i} + \varepsilon_{1i} \text{ if } G_i = 1 \quad (3)$$

$$Y_{0i} = \alpha_{01} J_{01i} + \varepsilon_{0i} \text{ if } G_i = 0 \quad (4)$$

where variables Y_1 and Y_0 represent household food security under secure land tenure and insecure land tenure respectively. J_1 and J_0 are vectors of independent variables explaining the outcome variables Y_1 and Y_0. Y_1 and Y_0 are observable based on the criteria presented in equation 2. Ordinary Least Square (OLS) estimates was biased as the study suffered from sample selection bias and the errors ε_{1i} and ε_{0i} conditional to the sample selection criterion had a non-zero value (Lee and Trost, 1978; Maddala, 1983). The error terms, μ ε_1 and ε_0 are assumed to have a tri-variate normal distribution with a 0 mean and non-singular covariance matrix Σ that is $(\mu, \varepsilon_1, \varepsilon_0)' \approx N(0, \Sigma)$ as shown in equation 5.

$$\text{With } \Sigma = \begin{bmatrix} \sigma^2_{\varepsilon 1} & \sigma_{\varepsilon 1 \varepsilon 0} & \sigma_{\varepsilon 1 \mu} \\ \sigma_{\varepsilon 1 \varepsilon 0} & \sigma^2_{\varepsilon 0} & \sigma_{\varepsilon 0 \mu} \\ \sigma_{\varepsilon 1 \mu} & \sigma_{\varepsilon 0 \mu} & \sigma^2_{\mu} \end{bmatrix} \quad (5)$$

where σ^2_μ represent the variance of the error in the criterion equation 1 assumed to be equal to 1 since according to Maddala (1983) the coefficients are estimated up to a scale factor. $\sigma^2_{\varepsilon 1}$, and $\sigma^2_{\varepsilon 0}$ represents the variance of ε_1 and ε_0 respectively in outcome equation in 3 and 4 respectively. The values $\sigma_{\varepsilon 1 \mu}$ and $\sigma_{\varepsilon 0 \mu}$ are the covariance of error terms μ, ε_1 and ε_0. As suggested by Maddala (1983), the outcome of equation 3 and 4 is not observed simultaneously and hence the covariance between and are not defined. Since the error μ of equation 1 is correlated with the error terms of the outcome equation 3 and 4, the expected values of the error terms were not equal to zero given the sample selection bias as expressed in equations 6 and 7.

$$E[\varepsilon_{1i} | G_i = 1\rangle] = \sigma_{\varepsilon 1 \mu} \frac{\phi(\beta X_i / \sigma)}{\phi(\beta X_i / \sigma)} \equiv \sigma_{\varepsilon 1 \mu} \lambda_{1i} \quad (6)$$

$$E[\varepsilon_{0i} | G_i = 0\rangle] = -\sigma_{\varepsilon 0 \mu} \frac{\phi(\beta X_i / \sigma)}{1 - \phi(\beta X_i / \sigma)} \equiv \sigma_{\varepsilon 0 \mu} \lambda_{0i} \quad (7)$$

where ø (.) and ø (.) represent the standard normal probability density function and normal cumulative density respectively. λ_{1i} and λ_{0i} is the inverse mills ratio representing the estimated ratio of ø (.) and ø (.) estimated at. If $\sigma_{\varepsilon 1 \mu}$ and $\sigma_{\varepsilon 0 \mu}$ are statistically significant, then, land tenure security and household food security were correlated hence evidence of endogeneity and presence of sample selection bias (Maddala and Nelson, 1975). Asfaw *et al.* (2012) suggest that, maximum likelihood estimation is an efficient method of estimating ESR. Considering the assumption of logarithmic likelihood function, the error distribution in equation 1, 3 and 4 can be expresses as in equation 8

$$LnL = \sum_{i=1}^{N} G_i \left[\ln \phi(\frac{\varepsilon_{1i}}{\sigma_{\varepsilon 1}}) - \ln \sigma_{\varepsilon 1} + \ln \Phi(\phi_{1i}) \right]$$
$$+ (1 - G_i) \left[\ln \phi(\frac{\varepsilon_{0i}}{\sigma_{\varepsilon 0}}) - \ln_{\varepsilon 0} + \ln(1 - \Phi(\phi_{0i})) \right]$$

where $\phi_{ji} = \frac{(\beta X_i + y_j \varepsilon_{ji} / \sigma_j)}{\sqrt{1 - y_j^2}}$, j=0,1 with representing the correlation coefficient between the error term (μ_i) of the criterion model in equation 1 and the errors (ε_{ji}) of the outcome equations 3 and 4.

Conditional expectations, treatment and heterogeneity effects. Since, ESR has the ability to estimate the effect of a variable for actual and counterfactual conditions as suggested by Di Falco *et al*. (2011), the study estimated the expected and counterfactual household food security under the two regimes. That is comparison of the expected household food security of the land tenure secure households (equation 9) with respect to the land tenure insecure household (equation 10) and to analyse the expected household food security in the counterfactual hypothetical (equation 11)) that the land tenure secure households are land tenure insecure, and (equation 11) that the land tenure insecure households are land tenure secure. This is the decision stage of the model. The observed household food security and counterfactual conditions are represented by equations 9, 10, 11 and 12.

$$E(y_s | A_i = 1) = X\beta_s + \sigma_{s\eta} \lambda_s \quad (9)$$

$$E(y_{ns} | A_i = 0) = X\beta_{ns} + \sigma_{ns\eta} \lambda_{ns} \quad (10)$$

$$E(y_{ns} | A_i = 1) = X\beta_{ns} + \sigma_{ns\eta} \lambda_{ns} \quad (11)$$

$$E(y_s | A_i = 0) = X\beta_s + \sigma_{s\eta} \lambda_s \quad (12)$$

Cases 9 and 10 along the diagonal of Table 2 show the actual observed expectations in the selected sample while cases 11 and 12 are the counterfactual expected outcomes.

Table 2. Treatment and heterogeneity effects

Sub-samples	Decision stage		Treatment effects
	Secure land tenure	Insecure land tenure	
Secure land tenure households	(9) $E(y_s \| A_i = 1)$	(11) $E(y_{ns} \| A_i = 1)$	TT
Insecure land tenure households	(12) $E(y_s \| A_i = 0)$	(10) $E(y_{ns} \| A_i = 0)$	TU
Heterogeneity effects	BH_1	BH_2	TH

where;
$A_i = 1$ is if households were land tenure secure while $A_i = 0$ is if households were land tenure insecurey_{S} represents household food security for land tenure secure households whereas y_{B} is the household food security for land tenure insecure households. On the treatment effects column, TT refers to the effect of treatment on the treated, TU denoted the effect of treatment on the untreated,BH_1 is the effect of base heterogeneity for land tenure secure households, BH_2 is the effect of base heterogeneity for land tenure insecure households, and TH =(TT-TU), the transitional heterogeneity.

In Table 2, the effect of treatment of the treated (TT) refers to the difference between expected value of the household food security (outcome variable) for land tenure secure households and the expected value of household food security if they were land tenure insecure (cells 9 and 11). The effect of treatment on the untreated (TU) is the difference between the expected household food security for land tenure insecure households and the expected value of household food security if they were land tenure secure (cells 12 and 10). Study used exclusion restrictions as instruments for the model to be identified. This is in addition to the already generated from the selection model of determinants of land tenure security. For instruments to be valid they must be directly correlated with endogenous/selection variable (land tenure security) but not outcome variable (household food security) (Di Falco *et al.*, 2011). Study used number of years' household had stayed on the land and the number of years the household had stayed on the ward as instruments in the model. A falsification test was carried out to determine the validity of the instruments and results presented in Appendix 1. Results show the selected instruments were valid since they are jointly significant determinants of land tenure security(model 1; X^2= 34.29; p=0.00) however they were not significant determinants of household food security as shown in Model 2 (F-statistics=5.25, p =0.000) while model 3 (F-statistics=5.38, p =0.00).

Results and Discussion

Results in Table 3 show that, on average, household heads in land tenure secure category were significantly older compared to those in the land tenure insecure category. Furthermore, land tenure secure households had fewer household members and more land than land tenure insecure households. Moreover, land tenure secure household heads had stayed on the land for more years and the household heads walked for more minutes to reach their parcels of land than land insecure households. Additionally, household heads from land tenure secure category reported higher food security and higher maize productivity levels compared to those with insecure land tenure. Majority of households with secure land tenure owned oxen an indication of availability of farm labour. Households heads from the land tenure category also acquired land through purchase and had fertile land.

Effect of land tenure security on household food security. Endogenous switching regression model results consist of two parts. The first part is the decision stage on the determinants of land tenure security as presented in Table 4.The second part is the effect of land tenure security on household food security as presented in Table 5.

Determinants of land tenure security. In order to take care of the possible endogeneity, the study used ESR model. Table 4 represents results of the first stage of the ESR model on the determinants of land tenure security. Household size, land acquisition through purchase, land fertility, period the household has stayed on the land, and walking time between the homestead and the parcel in minutes were found to be significantly influencing land tenure security. An increase in the household size by one member reduces the likelihood of being land tenure secure. More members in the household may translate to increase in incidences of land sub-division hence making it difficult to secure land (Valkonen, 2021). As the number of household members increase, the power to

Table 3. Description and measurement of variables used in the study

Variable Name	Description and measurement of variables	Insecure LT	Secure LT	Significance
Continuous variables		***Mean***		***t-statistic***
Age	Age of the household head in years	38.099	42.134	-3.343***
Education level	Years of schooling of the household head	8.331	8.754	-1.003
Household size	Number of people in the household	4.880	4.330	2.959***
Land stay	Number of years household has stayed on the land	14.268	18.058	-3.057***
Ward stay	Number of years household has stayed in the ward	26.662	27.103	-0.268
Land size	Total land size in Ha	1.347	1.838	-3.119***
Market access	Walking time from homestead to the nearest market in minutes	37.986	39.045	-0.326
Parcel access	Walking time from the homestead to the parcel in minutes	2.787	4.255	-4.639***
Road access	Walking time from the homestead to the nearest tarmac road in minutes	10.373	11.416	-1.110
Extension contacts	Number of contacts the respondent had with an extension agent	1.193	1.398	-1.491
Household food security	Level of food security	55.257	59.217	-2.226***
Maize productivity	Productivity of maize (Kg/Ha)	2309.972	2594.835	-2.137***
Household income	Total household income in KES	241567.700	266127.500	-1.117
Categorical variables		***Percentage***		X^2
Land tenure security	% of respondents as per the land tenure security category	38.800	61.200	
Sex	% of male decision makers	19.010	24.110	1.308
Marital status	% of married decision makers	70.420	69.200	0.062
Community leadership	% of household heads with community leadership	13.3800	16.960	0.849
Oxen ownership	% of respondents owning an oxen	10.560	22.320	8.226***
Credit access	% of respondents with access to credit	45.070	45.540	0.008
Group membership	% of respondents who are members of at least one group	71.130	76.790	1.468
Land concentration	% of respondents with land concentrated in one area	99.300	96.880	2.382
Land acquisition	% of respondents who acquired land through purchase	12.680	28.570	12.630***
Land topography	% of respondents with a hilly land	32.390	39.290	1.778
Land dispute	% of respondents with land disputes	9.860	10.710	0.068
Land fertility	% of respondents with fertile land	64.080	76.790	6.932***

*** represents significance level at 1%

control ownership of land reduce hence more likely to have insecure land tenure. However, in contrast to this finding, Ghebru and Lambrecht (2017) argue that, an increase in the members in the household may mean increase in food requirements hence may signal the household heads to secure the land so as to provide for their families.

Household who acquired land through purchase were more likely to be land tenure secure. The land purchasing process especially in areas with developed land markets is a structured and legal process hence after the process, there is likely to be security of land tenure. However, corruption by land markets participants such as government officials may pose a threat to the trust accorded to the land buying process (Djurfeldt, 2020). Land fertility also positively and significantly influenced land tenure security. Ownership of a fertile land increases the probability of household being land tenure secure. Fertile land is usually competitive in the land market and therefore owners are more likely to secure it to safeguard it from land grabbers. Coulibary (2021) argue that, due to the expected high productivity from fertile land, holders would secure it to maintain its stream of benefits.

Farmers who have stayed longer on the land are more likely to be land tenure secure. The longer a person stays on the land, the more likely they are to make investments such as planting trees. These investments may increase land tenure security. In areas using customary land tenure, land holders who have stayed longer on the land are viewed as part of the community and hence become more land tenure secure (Brasselle *et al.,* 2002). Land tenure security was also influenced by the access to the parcel of land. The more time it takes to reach the parcel from the homestead, the more land tenure secure it is. Distant parcels are more exposed to land grabbers and hence it's reasonable to secure it. Sitko *et al*. (2014) argue that, in scenarios where the owners are not seen on the land for some time due the long distance, people tend to

Table 4. Results of the determinants of land tenure security (first stage of ESR)

Variables	Standard Error	Coefficients
Socio-economic characteristics		
Sex	0.201	0.136
Marital status	0.181	-0.104
Age	0.0085	0.006
Education level	0.023	0.0101
Household size	0.044	-0.128***
Household income	3.871	2.071
Maize productivity	0.000059	4.871
Institutional characteristics		
Community leadership	0.218	-0.066
Land related characteristics		
Land size	0.046	0.048
Land concentration	0.617	-0.306
Land acquisition	0.188	0.762***
Land topography	0.157	0.082
Land dispute	0.240	0.106
Land fertility	0.175	0.387**
Land stay	0.0088	0.019**
Parcel access	0.034	0.155***
Model fit results		
Constant	0.807	-0.597
Number of observations		366
Log likelihood		-205.091
Prob>ch^2		0.000

, * represents significance level at 5%, and 1% respectively assume they are absentee landlords hence grab the land. Thus such landlords are more likely to secure the land.

Effects of land tenure security on household food security. The Wald test results (46.16) in the endogenous switching regression model (Table 5) indicate that is significant at 1% level hence implying a goodness of fit of the model. Additionally, it suggests the presence of endogeneity problem and hence justifying the use of ESR. The likelihood ratio test of independence equations that is the selection and outcome equations (X^2 =3.430, P = 0.0) is positive and significant at 10% indicating that the two equations are positively correlated. This implies that, land tenure security is positively correlated with household food security. The negative and significant (/ro 0= -0.033, P = 0.0; /ro1= -1.017, P = 0.000) coefficients imply that farmer with higher household food security were likely to self-select themselves to be land tenure secure.

Results in Table 5 column 1 and 2 which represents the second stage of the ESR model indicate that, marital status, age, education level, household size, household income, maize productivity, number of contacts with an extension agent, ownership of an oxen, and credit access significantly influenced household food security. Married people were more likely to be food secure than the unmarried ones. Marriage in most African societies is meant support to each other both emotionally and economically and therefore this could lead to improved food security. Similarly, Djangmah (2016) and Amadu *et al*. (2021) argue that, married people pool their resources together hence reduce costs. Additionally, married people are likely to save some resources to help them during times of low income hence smoothen their lives. However, Aidoo *et al*. (2013) and Akukwe (2020) suggest that unmarried people would be more food secure due to their possible smaller household size hence fewer mouths to feed than married people.

Older household heads were more likely to be food secure for both secure and insecure land tenure households. Older farmers may have more experience in food production than the younger ones which would likely increase their food security. Wekesa *et al*. (2018) argue that, older farmers may have accumulated more social and physical capital hence able to adopt latest technologies for food production. However, Kassie *et al*. (2016) suggest that, due to the labour intensive nature of agriculture, which may require healthy and energetic people, older farmers may not be able to produce enough food. Additionally, older farmers may not be aware of the latest production technologies. Older farmers may have reduced the contribution towards welfare contributions such as food security (Yahaya *et al.,* 2018; Oluwatayo and Ojo, 2019).

Better educated household heads increase their likelihood of being food secure for the land tenure insecure category. Education exposes individuals to information on better and latest technologies which could increase food production. Similarly, Lutomia *et al*. (2019) argue that better educated people are likely to be more innovative and have more knowledge to access productive resources. Additionally, Fiaz *et al*. (2018) and Habtewold (2018) suggest that educated household heads may be more ready to update their agricultural knowledge and thus improve food security. Household size negatively influence household food security. Larger households reduce the probability of being food secure for the households in land tenure secure category. Increase in household size may mean increase in the number of people to feed and therefore households may likely be food insecure even with secure land tenure. Ogunniyi *et al*. (2018) argue that, households with many members may have other priority expenses and thus lack enough finances to invest in adoption of new agricultural technology to produce food. Larger households may indicate higher burden to feed them (Tiwasing *et al.,* 2018; Lutomia *et al.,* 2019).

Table 5. Results of the ESR model on the effect of land tenure security on household food security (second stage of the ESR)

Variables	Column 1, LTS=0		Column 2, LTS=1	
	Standard Error	Coefficients	Standard Error	Coefficients
Socio-economic characteristics				
Sex	3.543	0.305	2.453	-2.036
Marital status	2.672	4.839*	2.307	7.392***
Age	0.109	0.052	0.099	0.178*
Education level	0.373	0.850**	0.274	0.282
Household size	0.649	-0.073	0.594	-1.179**
Household income	0.0004	-0.0009***	0.274	0.000**
Maize productivity	0.001	0.003***	0.001	0.003***
Institutional characteristics				
Market access	0.037	0.029	0.037	-0.046
Extension contacts	1.102	0.428	0.818	1.956**
Oxen own	3.906	7.046*	2.533	2.111
Group membership	2.723	2.837	2.300	2.730
Credit access	2.403	3.599	1.962	8.621***
Land related characteristics				
Land size	0.758	0.434	0.478	-0.095
Constant	8.631	34.196***	7.253	39.447***
/lns0	0.059	2.567***		0.059
/lns1	0.108	2.827***		0.108
/r0	0.482	-0.033*		0.482
/r1	0.359	-1.017***		0.359
sigma0		13.024		0.772
sigma1	16.901	1.819		
rho0	-0.033	0.481		
rho1	-0.768	0.147		
LR test of independent equations	Chi(2)=3.430*			
Wald chi2(13) 46.16***				

*, **, *** represents significance level at 10%, 5%, and 1% respectively

Increase in household income decreases the likelihood of being food secure for the land tenure secure households while it increased the likelihood of being food secure for the households with land tenure security. For the unsecure land tenure households, they would probably use the increased in income to secure their land instead of food production. Land secure household on the other would invest in modern technologies to increase their food production (Ahmed *et al.,* 2017). Ibrahim *et al*. (2016) indicate that, higher incomes can be used to purchase food commodities hence improve food security status. In contrast with the study finding, Habtewold (2018) argues that high income earners may invest in other commercial activities such as horticultural production where prices are highly unstable. Maize productivity also positively and significantly influenced household food security. Higher maize productivity increases the probability of being food secure for both secure and insecure land tenure households. In Kenya maize is considered as a staple food and therefore having more maize imply being food secure. Increased maize productivity translates to increased food on the table and hence increased food security (Santpoort, 2020).

Increase in the number of contacts with an extension agent positively influences the secure land tenure farmer's likelihood of being food secure. More contacts with an extension agent could increase the farmers' knowledge on the latest agricultural technologies which may be used to increase food production. Extension services are key in promotion of farmer innovative technologies and awareness creation on how to implement dietary needs for the nation (Fiaz *et al.,* 2018). Al-Shayaa *et al*. (2012) indicate that extension agents have a role in advocating government policies geared towards the fight against food insecurity through advocating for the use of modern agricultural technology, and access to affordable credit and inputs.

Oxen ownership by the land tenure unsecure households increases their likelihood of being food secure. Oxen is a source of agricultural labour in the rural areas hence increase food production. Similarly, Mohammed and Mohammed (2021) found out that, oxen could be used to cultivate land and carry out other farm operations hence a key component in improving household food security. Additionally, oxen in some societies can be hired out to provide income that could be used to purchase food (Habtewold, 2018; Awoke *et al.,* 2022).

The land tenure secure households with access to credit facilities were more likely to be food secure. Credit obtained could be used to invest in new agricultural technologies meant to boost food production in the household. Contrary to the study findings, Ibrahim *et al*. (2016) and Lutomia *et al*. (2019) argue that, credit may lead to food insecurities since a significant part of the household income may be used for repayment instead of purchasing food.

Endogenous switching regression impact estimates. Results of estimates for the average treatment effects on the treated (ATT), average treatment effects for the untreated (ATU) and heterogeneity effects (HE) are shown in Table 6. The results present the effect of land tenure security on household food security and also the effects of inherent characteristics of household food security. Results of the casual effects (TE) of food consumption score for land tenure secure household are approximately 2.273 and about 20.996 for insecure land tenure households if they were land tenure secure. Results of the expected household food security under actual and counterfactual scenarios for land tenure secure households are cells (a and c) and land tenure insecure households cells (d and b). The expected household food consumption score by land tenure secure households is about 59.247 and 55.371 for the land tenure insecure households. Such a simple comparison may lead to inaccurate conclusions that, land tenure security increases household food security by about 7%.

The treatment effects for land tenure security on household food security are presented in the treatment effects column. In the counterfactual side cell c for land tenure secure households, the household food consumption score would have been approximately 56.973 representing about 4% decrease, if they were land tenure insecure. On the other hand, land insecure household's food consumption score would have increase to approximately 76.337 representing an increase of about 38% if they would have been land tenure secure. These results indicate land tenure security significantly increases household food security. The results are consistent with findings by Keovilignavong and Suhardiman (2020) who urged that, secure land tenure enables farm households to acquire credit facilities which would be invested on the farm hence increase food security. Similarly, Espinosa (2019) suggests that, land tenure secure household are more likely to carry out both long and short term farm investments that would increase their productivity hence increase food security.

CONCLUSION AND RECOMMENDATIONS

In conclusion, land tenure security improved the household food security status of the small holder farmers in the study area. This paper therefore contributes to the on-going debate on land governance in the following ways; Firstly, it re-focuses the attention of land sector stakeholders such as researchers and government not just view land title deed as a panacea to land insecurity challenges but realize that rights to use and transfer of land can also play a critical role in shaping land tenure security landscape especially in the rural areas. Secondly, it unpacks the nexus between land tenure security and food security while identifying the rural farm household's position in the linkage. Thirdly, the paper employs an innovative econometric model (endogenous switching regression model) to analyse the role of land tenure security on household food security while taking care of the possible self-selection and endogeneity problems. This will in turn assist future researchers in identification and solving endogeneity and self-selection problems. Lastly, from a policy point of view, it calls for government and other stakeholders to broaden the view that land is not just a physical space but it's a factor of production with significant implications on the welfare of rural communities.

Table 6. Average treatment effects on the treated (ATT) and average treatment effects for the untreated(ATU)

Sub-samples	Decision stage		Treatment effects	t-value
	Secure land tenure	Insecure land tenure		
Households with secure land tenure	(a) 59.247	(c) 56.973	2.273***	3.926
Households with insecure land tenure	(d) 76.337	(b) 55.371	20.966***	33.350
Heterogeneity effects	-17.090	1.602	-18.693	

*** represents significance level at 1%

ACKNOWLEDGEMENT

The authors express their gratitude to the German Academic Exchange Service (DAAD) through the African Economic Research Consortium (AERC) for funding this study.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Ahmed, U. I., Ying, L., Bashir, M. K., Abid, M. and Zulfiqar, F. 2017. Status and determinants of small farming households' food security and role of market access in enhancing food security in rural Pakistan. *PloS One* 12 (10): 1–15.

Aidoo, R., Mensah J. O. and Tuffour T. 2013. Determinants of household food security in the Sekyere-Afram Plains District of Ghana. pp. 514-521. In: 1st Annual International Interdisciplinary Conference, AIIC, Proceedings, Azores, Portugal

Ajefu, J. B. and Abiona, O. 2020. The mitigating impact of land tenure security on drought-induced food insecurity: Evidence from Rural Malawi. *Journal of Development, Studies* 56 (12): 2169-2193. doi:10.1080/00220388.2020.

1762862

Akukwe, T. I. 2020. Household food security and its determinants in agrarian communities of southeastern Nigeria. *Agro-Science* 19 (1): 54-60.

Al-Shayaa, M. S., Baig, M. B. and Straquadine, G. S. 2012. Agricultural extension in the Kingdom of Saudi Arabia: Difficult present and demanding future. *Journal Animal Plant Science* 22 (1): 239-246.

Amadu, I., Seidu, A. A., Duku, E., Okyere, J., Hagan, J. E., Hormenu, T. and Ahinkorah, B. O. 2021. The joint effect of maternal marital status and type of household cooking fuel on child nutritional status in sub-Saharan Africa: analysis of cross-sectional surveys on children from 31 countries. *Nutrients* 13 (5): 1541.

ANGOC. 2017. From the Farmland to the Table: Exploring the Links between Tenure and Food Security. Quezon: Asian NGO Coalition for Agrarian Reform and Rural Development and Global Land Tool Network.

Asfaw, S., Shiferaw, B., Simtowe, F. and Lipper, L. 2012. Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food Policy* 37 (3): 283-295.

Awoke, W., Eniyew, K., Agitew, G., and Meseret, B. 2022. Determinants of food security status of household in Central and North Gondar Zone, Ethiopia. *Cogent Social Sciences* 8 (1): 2040138.

Bamire, A. S. 2010. Effects of tenure and land use factors on food security among rural households in the dry Savannas of Nigeria. African Journal of Food, Agriculture, Nutrition and Development 10 (1):1982-2000.

Besley, T. 1995. Property rights and investment incentives: Theory and evidence from Ghana. *Journal of Political Economy* 103 (5): 903-937.

Brasselle, A.-S., Gaspart, F. and Platteau, J.-P. 2002. Land tenure security and investment incentives: puzzling evidence from Burkina Faso. *Journal of Development Economics* 67: 373-418.

Coulibaly, D. A. 2021. An analysis of the Impact of Land Tenure Security on Agricultural Productivity in Burkina Faso. African Economic Research Consortium. 395

County Government of Narok. 2018. Narok County Integrated Development Plan (2018-2022), Nairobi: Government of Kenya.

Deininger, K. and Castagnini, R. 2006. Incidence and impact of land conflict in Uganda. *Journal of Economic Behavior and Organization* 60 (3): 321-345.

Deininger, K. and Jin, S. 2006. Tenure security and land-related investment: Evidence from Ethiopia. *European Economic Review* 50(5): 1245-1277.

Di Falco, S., Veronesi, M. and Yesuf, M. 2011. Does adaptation to climate change provide food security? A micro perspective from Ethiopia. *American Journal of Agricultural Economics* 93 (3): 829-846.

Djangmah, G. M. 2016. Comparative analysis of food security status of farming households in Eastern and Northern Regions of Ghana (Unpublished MSc Project). Department of Agricultural Economics, McGill University, Montreal; Quebec, Canada.

Djurfeldt, A. A. 2020. Gendered land rights, legal reform and social norms in the context of land fragmentation - A review of the literature for Kenya, Rwanda and Uganda. *Land Use Policy* 90: 101-115.

Espinosa-Cristia, J. F., Feregrino, J. and Isla, P. 2019. Emerging, and old, dilemmas for food security in Latin America. *Journal of Public Affairs* 19 (3):1999.

FAO, IFAD, UNICEF, WFP and WHO. 2021. The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition, and affordable healthy diets for all. Rome, Food Agriculture Organization of the United Nations.

Fiaz, S., Noor, M. A. and Aldosri, F. O. 2018. Achieving food security in the Kingdom of Saudi Arabia through innovation: Potential role of agricultural extension. *Journal of* *the Saudi Society of Agricultural Sciences* 17 (4): 365-375.

Food and Agriculture Organization. 1996. Rome declaration on world food security and world food. Rome: Food and Agriculture Organization.

FAO, IFAD, UNICEF, WFP and WHO. 2022. The State of Food Security and Nutrition in the World 2022. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, Food Agriculture Organization of the United Nations.

Ghebru, H. and Holden, S. 2013. Links between tenure security and food security: Evidence from Ethiopia (No. 02/13). Centre for Land Tenure Studies Working Paper.

Ghebru, H. and Lambrecht, I. 2017. Drivers of perceived land tenure (in) security: Empirical evidence from Ghana. *Land Use Policy* 66: 293-303.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F. and Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people. *Science* 327 (5967):812-818.

Government of Kenya 2021. The national agricultural research systems policy. Ministry of agriculture, livestock, fisheries and cooperatives. Nairobi, Kenya.

Habtewold, T. M. 2018. Determinants of food security in the Oromiya Region of Ethiopia. pp. 39-65. In: Economic growth and development in Ethiopia. Springer, Singapore.

Higgins, D., Balint, T., Liversage, H. and Winters, P. 2018. Investigating the impacts of increased rural land tenure security: A systematic review of the evidence. *Journal of Rural Studies* 61:34-62.

Holden, S. T. and Ghebru, H. 2016. Land tenure reforms, tenure security and food security in poor agrarian economies: Causal linkages and research gaps. *Global Food Security* 10: 21-28.

Holden, S. T. and Otsuka, K. 2014. The roles of land tenure reforms and land markets in the context of population growth and land use intensification in Africa. *Food Policy* 48: 88-97.

Holden, S. T., Otsuka, K. and Deininger, K. 2013. Land tenure reforms, poverty and natural resource management: conceptual framework. pp. 1-26. In: Land Tenure Reform in Asia and Africa. Palgrave Macmillan, London.

Ibrahim, H. Y., Adeola, S. S. and Ibrahim, H. I. 2016. Determinants of food insecurity among farming households in Katsina state, North Western Nigeria: An ordinal logit regression approach. *Journal of Agricultural Sciences* 61 (3): 291–301.

Kariuki, P. M., Njoka, J. T., Saitabau, L. C. and Saitabau, H. S. 2016. Forest Governance, Livelihoods and Resilience: The Case of Loita Forest (Entime e Naimina enkiyio), Narok County, Kenya. Swirtz: Springer International Publishing Switzerland 2016. OI 10.1007/978-3-319-19405-9_6

Kassie, M., Jaleta, M. and Mattei, A. 2014. Evaluating the impact of improved maize varieties on food security in Rural Tanzania: Evidence from a continuous treatment approach. *Food Security* 6 (2): 217-230.

Kassie, M., Zikhali, P., Pender, J. and Kohlin, G. 2016. The economics of sustainable land management practices in the Ethiopian highlands. *Journal of Agricultural Economics* 61: 605–27.

Kennedy, G., Razes, M., Ballard, T. and Dop, M. C. 2010. Measurement of dietary diversity for monitoring the impact of food based approaches. In International symposium on food and nutrition security, Rome.

Kennedy-Lazar, M. 2016. Linking Food and Land Tenure Security in the Lao PDR. Vientiane: Global Association for People and the Environment.

Kenya National Bureau of Statistics. 2019. Kenya Population and Housing Census 2019. Nairobi: Government of Kenya.

Keovilignavong, O. and Suhardiman, D. 2020. Linking land tenure security with food security: Unpacking farm households' perceptions and strategies in the rural uplands of Laos. *Land Use Policy* 90: 1-11.

Lawry, S., Samii, C., Hall, R., Leopold, A., Hornby, D. and Mtero, F. 2017. The impact of land property rights interventions on investment and agricultural productivity in developing countries: a systematic review. *Journal of Development Effectiveness* 9 (1): 61-81. doi:10.1080/19439342.2016.1160947

Lee, G. H., and Trost, R. P. 1978. Estimation of some limited dependent variable models with application to housing demand. *Journal of Econometrics* 8 (3): 357-382.

Linkow, B. 2016. Causes and consequences of perceived land tenure insecurity: Survey evidence from Burkina Faso. *Land Economics* 92(2): 308-327.

Lovo, S. 2016. Tenure insecurity and investment in soil conservation. Evidence from Malawi. *World Development* 78: 219-230.

Lutomia, C. K., Obare, G. A., Kariuki, I. M. and Muricho, G. S. 2019. Determinants of gender differences in household food security perceptions in the Western and Eastern regions of Kenya. *Cogent Food and Agriculture* 5 (1): 1694755. doi.org/10.1080/23311932.2019.1694755

Maddala, G. S. 1986. Limited-dependent and qualitative variables in econometrics (No. 3). Cambridge university press.

Maddala, G. S. and Nelson, F. D. 1975. Specification errors in limited dependent variable models (No. w0096). National Bureau of Economic Research.

Mallick, D. and Rafi, M. 2010. Are female-headed households more food insecure? Evidence from Bangladesh. *World Development* 38 (4): 593-605.

Maxwell, D. and Wiebe, K. 1999. Land Tenure and food security: A review of concept, evidence and methods. *Journal of Development and Change* 30 (1999): 825-849.

Mekureyaw, M. F. 2017. Maize Lethal Necrosis Disease an Emerging Problem for Maize Production in Eastern Africa. *Journal of Plant Physiology and Pathology* 5 (4): 2-8. doi:10.4172/2329-955X.1000170

Mendola, M. and Simtowe, F. 2015. The welfare impact of land redistribution: Evidence from a quasi-experimental initiative in Malawi. *World Development* 72: 53-69. doi:dx.doi.org/10.1016/j.worlddev.2015.02.010

Migot-Adholla, S. E., Place, F. and Oluoch-Kosura, W. 1994. Security of tenure and land productivity in Kenya. Iowa: Hunt Publishing Company.

Mohammed, S. and Mohammed, A. 2021. Determinants of Food Security: The Case of Kurmuk District in Benishangul Gumuz Regional State, Western Ethiopia. *International Journal of Natural Resource Ecology and Management* 6 (1):16-26.

Moreda, T. 2018. Contesting conventional wisdom on the links between land tenure security and land degradation: Evidence from Ethiopia. *Land Use Policy* 77: 75-83.

Nagarajan, L., Naseem, A. and Pray, C. 2019. Contribution of policy change on maize varietal development and yields in Kenya. *Journal of Agribusiness and Emerging Economies* 9 (1):4-21. doi:https://doi.org/10.1108/JADEE-01-2018-0013

Ogunniyi, A., Omonona, B., Abioye, O., and Olagunju, K. 2018. Impact of irrigation technology use on crop yield, crop income and household food security in Nigeria: A treatment effect approach.*AIMS Agriculture and Food* 3 (2): 154–171.

Oluwatayo, I. B. and Ojo, A. O. 2019. Effect of access to ICT on food insecurity among farming households in Nigeria. *The Journal of Developing Areas* 53 (2): 155–168.

Payne, H. E., Gray, B., Davis, S. F., Hine, C. A., Das, A., Kabra, M. and Crookston, B. T. 2016. Factors associated with food insecurity among women and children in rural Rajasthan, India. *Journal of Gender, Agriculture and Food Security (Agri-Gender)* 1 (302-2016-4757): 23-39.

Pinckney, T. C. and Kimuyu, P. K. 1994. Land tenure reform in East Africa: Good, bad or unimportant? *Journal of African Economies* 3 (1):1-28.

Place, F. 2009. Land tenure and agricultural productivity in Africa: A comparative analysis of the economics literature and recent policy strategies and reforms. *World Development* 37 (8): 1326-1336.

Santpoort, R. 2020. The drivers of maize area expansion in Sub-Saharan Africa. How policies to boost maize production overlook the interests of smallholder farmers. *Land* 9 (3): 68-81.

Sitko, N. J., Chamberlin, J. and Hichaambwa, M. 2014. Does smallholder land titling facilitate agricultural growth? An analysis of the determinants and effects of smallholder land titling in Zambia. *World Development* 64: 791-802.

Stata Corp 2014. Stata statistical software: release 15. Stata Corporation. LP, College Station, Texas, United States of America.

Tibesigwa, B., and Visser, M. 2016. Assessing gender inequality in food security among small-holder farm households in urban and rural South Africa. *World Development* 88: 33-49.

Tiwasing, P., Dawson, P. and Garrod, G. 2018. Food security of rice-farming households in Thailand: A logit analysis. *The Journal of Developing Areas* 52 (1): 85–98. doi:10.1353/jda.2018.0006

Valkonen, A. 2021. Examining sources of land tenure (in) security. A focus on authority relations, state politics, social dynamics and belonging. *Land Use Policy* 101: 105191.

Wekesa, B. M., Ayuya, O. I. and Lagat, J. K. 2018. Effect of climate smart agricultural practices on household food security in smallholder production systems: micro level evidence from Kenya. *Agriculture and Food Security* 7 (80): 1-14. doi.org/10.1186/s40066-018-0230-0

World Food Programme 2022. Global Report on Food Crisis. Retrieved on May 29th 2022. https://www.wfp.org/publications/global-report-food-crises-2022

Yahaya, I., Pokharel, K. P., Alidu, A. F. and Yamoah, F. A. 2018. Sustainable agricultural intensification practices and rural food security: The case of North-western Ghana. *British Food Journal* 120 (2): 468–482.

African Journal of Rural Development, Vol 7(1) January-April 2022: pp. 38-52. ISSN 2415-2838

Distribution of *Fusarium s*pp. agents responsible for Fusarium Wilt of banana in Southern Benin

H. G. TOESSI[1,2,] M. ZANDJANAKOU-TACHIN[1], C. BRAHIMA[2] and K. DAOUDA[2]
[1]Laboratory of Plant Pathology, National University of Agriculture (UNA), 01 BP : 55 Porto-Novo, Benin
[2]Laboratory of Plant Physiology, UFR Biosciences, University Félix HOUPHOUET-BOIGNY, 22 BP : 582 Abidjan 22, Côte d'Ivoire
Corresponding Author: habib.toessi@yahoo.com
ORCID ID : https://orcid.org/0000-0001-9061-5110

ABSTRACT
Fusarium wilt of banana caused by *Fusarium oxysporum* f. sp. *cubense* is one of the most important fungal diseases in banana growing areas. It constitutes a major problem for the intensification of banana production in Republic of Benin. This study analyzed the phenotypic and pathogenic diversity of Fusarium strains with a view to sustainable control. A survey was carried out in 72 fields located in eight (8) communities (Missrété, Sakété, Adja-Ouèrè, Avrankou, Adjara, Ifangni, Tori and Allada) to assess the prevalence of banana Fusarium wilt. The communities of Avrankou showed a low percentage (12.59%) of disease incidence while the highest (61.11%) was recorded in the commune of Missrété. During survey, 11 banana varieties were identified, such as, "Avlan", "Planta", "Ganhikokoé", "Akpagbo", "Gbogui", "Goukokoé", "Sotunmon", "PITA3", "Péripita", "CRBP755", "50C". The cultivar "Avlan" was found to be the most susceptible to Banana Fusarium wilt with 63.30% disease incidence. The phenotypic characterization performed on 86 isolates resulting from the samples of different origins, was able to identify two groups of isolates proving to be similar in terms of behavior towards the various tests carried out. These were *Fusarium oxysporum* with 77 isolates and *Fusarium graminearum* with 09 isolates. The results of the pathogenicity tests highlighted the symptoms of *Fusarium oxysporum* observed in the field. This is the first time that Fusarium wilt of banana has been reported in Benin.

Key words: Bananas, Benin, *Fusarium oxysporum*, Fusarium wilt, isolates

RÉSUMÉ
La fusariose du bananier causée par *Fusarium oxysporum* f. sp. cubense est l'une des maladies fongiques les plus importantes dans les zones de culture de bananes. Elle constitue un problème majeur pour l'intensification de la production de bananes au Bénin. Cette étude a analysé la diversité phénotypique et pathogénique des souches de Fusarium en vue d'un contrôle durable. Une enquête a été réalisée dans 72 champs situés dans huit (8) communautés (Missrété, Sakété, Adja-Ouèrè, Avrankou, Adjara, Ifangni, Tori et Allada) pour évaluer la prévalence de la fusariose du bananier. Les communautés d'Avrankou ont montré un faible pourcentage (12,59 %) d'incidence de la maladie, tandis que le plus élevé (61,11 %) a été enregistré dans la commune de Missrété. Au cours de l'enquête, 11 variétés de bananes ont été identifiées, telles que "Avlan", "Planta", "Ganhikokoé", "Akpagbo", "Gbogui", "Goukokoé", "Sotunmon", "PITA3", "Péripita", "CRBP755", "50C". La variété "Avlan" s'est avérée être la plus susceptible à la fusariose du bananier avec une incidence de la maladie de 63,30 %.

Cite as: Toessi G. H.., Zandjanakou-tachin, M., Brahima, C. and Kone D. 2022. Distribution of *Fusariu*m Spp. agents responsible for Fusarium Wilt of banana in Southern Benin. *African Journal of Rural Development* 7 (1): 38-52.

Recieved: 28 June 2020
Accepted: 31 December 2021
Published: 30 April 2022

La caractérisation phénotypique réalisée sur 86 isolats provenant d'échantillons d'origines différentes a permis d'identifier deux groupes d'isolats présentant des comportements similaires aux différents tests effectués. Il s'agissait de *Fusarium oxysporum* avec 77 isolats et de *Fusarium graminearum* avec 09 isolats. Les résultats des tests de pathogénicité ont mis en évidence les symptômes de *Fusarium oxysporum* observés sur le terrain. C'est la première fois que la fusariose du bananier est signalée au Bénin.

Mots-clés : Bananes, Bénin, F*usarium oxysporum*, fusariose, isolats

INTRODUCTION

The banana plant, originating from Southeast Asia (Gowen, 1994) with tropical requirements, is a fruit tree belonging to the Musaceae family whose fruits are generally bananas. In recent years, world banana production has increased from 108.7 million tonnes in 2010 to over 112 million tonnes in 2016, of which about 20% is traded internationally and the remaining 80% is consumed locally (FAOSTAT, 2017). As for Africa, a production of 20.8 million tons is estimated and comes in third place (17.5%) after Asia (55.1%) and Americas (25.3%) (FAOSTAT, 2017). In the Republic of Benin, banana is one of the main self-consumption crops of the population. The annual national production of this crop is estimated at 20756 tons in 2016 for a yield of 48048 hg/ha with a total harvested area of 4320 ha (FAOSTAT, 2017). Like cassava, rice, maize and palm oil, banana is an important source of household income (Dhed'a *et al*., 2011). Banana varieties grown in Benin are generally distinguished by their color, taste, size, fruit shape, etc. (Dhed'a *et al*., 2011). They are: "SOTOUNMON"; "DOHEZE"; "DANKOEKOE"; "TCHON"; "LIMU"; "GUNKOEKOE"; "SOKOEKOE"; "GBOGUI"; "HLO". They are cultivated all over the country.

Globally, banana (which includes the dessert and plantain type bananas) is the main fresh fruit subject of important international trade. Its socio-economic and nutritional importance is considerable because, far from being a simple dessert, bananas play an essential role in the food security of over 400 million people in tropical countries. It is also a source of employment and income for local populations (Arias *et al*., 2003). Although there has been an increase in global banana production, bananas are subject to numerous parasitic constraints, among which fungal diseases contribute significantly to the decline in yields in different types of production (Daniells, 2009). These losses are observed through the net reduction of plant growth, size and weight of the bunch. For example, when plants are severely affected, the reduction of the bunch weight can be as high as 78% (Kangire, 1998). The pathogens responsible for the disease can be of various origins (Carlier *et al*., 2003).

Fusarium wilt caused by *Fusarium oxysporum* f. sp. cubense (Zambrano *et al*., 2007), is considered as one of the most important banana fungal diseases (Lassoudière, 2007). Four biovars have been identified in *Fusarium oxysporum* by their ability to infect a specific banana cultivar (Groenewald, 2006). The symptoms are, uniform yellowing of older to youngest leaves, necrosis of the stipe and browning of the vascular, root and rhizome systems (Do *et al*., 2001). Fusarium wilt was first described in 1876 in Australia on the cultivar Gros Michel (Carlier *et al*., 2003) and in 1952, in Kenya on the cultivar Bluggoe (Kung'u, 1995). In the Republic of Benin, banana fusarium wilt has never been reported, but characteristic symptoms of this disease have been observed in several Beninese banana plantations. However, abiotic factors can promote the development of such symptoms (Van Ee, 1999). More so, these symptoms can be confused with those of bacterial infection caused by race 2 of *Ralstonia solanacerum* (Ploetz *et al*,. 2003). Faced with the threat posed by Fusarium species, it is important to establish the Fusarium species in Republic of Benin in order to set up adequate disease control strategies against this pathogen. This study therefore aimed to constitute a large collection of Fusarium isolates relating to the spread of Fusarium wilt in banana plantations in Southern part of Republic of Benin and to analyze the phenotypic and pathogenic diversity of Fusarium strains with a view to sustainable control.

MATERIAL AND METHODS

Study areas and sampling. The various surveys were carried out in eight main banana production zones (communes) in the Republic of Benin (Fig 1). Nine banana fields in each commune were chosen, about 25 kilometers apart. In total, 60 banana fields were chosen for systematic surveys. On each of these plots, 30 banana trees representative were chosen at random and used for the collection of different data.

Plant material and soil. Fragments from leaves and root were taken at random from five infected plants with pruning shears (Figs. 2 and 3). About 5 g of soil samples were taken at the base of the five infected bananas, at a depth of 20 to 30 cm, over a radius of 2 m (Fig 4). The samples were taken while maintaining aseptic conditions as much as possible and avoiding direct contact between the different samples. Each sample was placed in a paper envelope bearing indications relating to its origin (date of sampling, variety, density, etc.). The organs thus harvested were transferred to the laboratory for isolation.

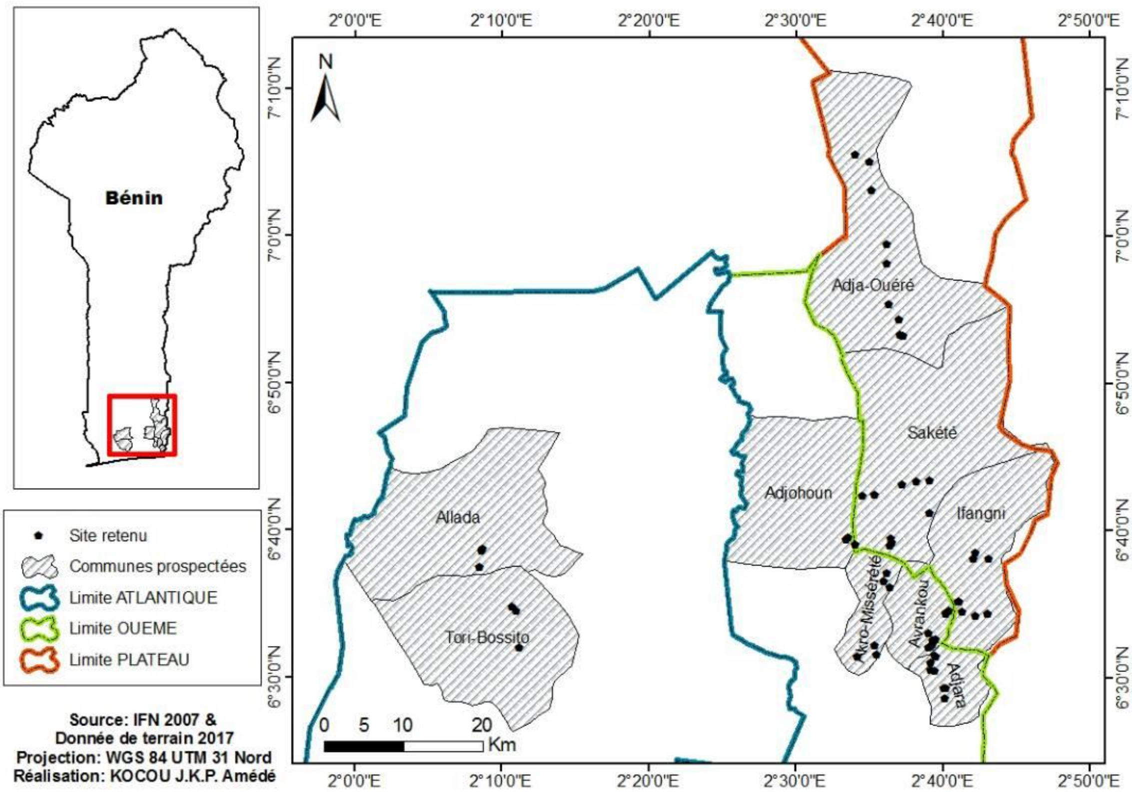


Fig.1 : Study areeas

Fig. 2 : Infected banana root

Fig. 3 : Infected banana leaft

Fig. 4 : Soil of the infected banana

Subsquently, samples were taken for morphological, physiological and pathogenic characterizations of the fungal collection obtained.

Isolation of fungi from banana leaves and roots. The fungi were isolated from fragments of infected banana leaves and roots. Fragments of 4 to 7 mm, disinfected with 70 alcohol, were cut and then deposited on PDA (Potato Dextro Agar) culture medium contained in 9 cm Petri dishes and incubated at 25 ± 2°C for 5 to 8 days. After development of the fungal colonies, the purification step was carried out using the successive sub-culturing technique, based on macro morphological cultural characters.

The soil adhering to the roots of the infected banana plants was collected, dried at 30°C and ground in a sterilized mortar. The fungi were isolated by taking 5 g of soil to which 3 ml of sterile distilled water was added. Then, 7 deposits of the peat obtained were made using a toothpick on PDA medium. The pure cultures were obtained by the purification process indicated above and the experiment was repeated three times.

Purification and identification of isolates. The purification of the isolates consisted of having a pure culture by successive subculturing of an isolated colony. After 48 to 72 hours of incubation, fragments in form of mycelial discs were cut out under sterile conditions on the growth front of the previous culture media and sub cultured onto new PDA culture media under the same conditions. These subcultures were repeated until colonies of pure appearance were obtained. The identification of isolates was carried out according to morphological characteristics using the criteria of the identification key described by Djerbi (1990).

The various fungal colonies obtained from cultures aged seven days on PDA culture medium, incubated at 25 ± 2°C. were described macroscopically and then observed under an optical microscope X40 resolution in order to identify them. The microscopic observation took into account the shape, the size of the spores, the presence or absence of chlamydia spores, the partitioning and the branching or not of mycelium. The isolation frequency (IF) of isolates of *Fusarium* spp. is estimated by the number of isolates obtained from a sample (NI) out of the total number of isolates obtained (NTI).

$$IF = \frac{NI}{TNI} x\ 100 \quad (1)$$

IF: Isolation Frequency

NI: Number of Isolates in a sample

TNI: Total Number of Isolates obtained

Pathogenicity tests. The inoculum was prepared from the 7-days old culture of *Fusarium* spp. The surface charged with conidia and immersed with 10 ml of distilled water was scraped using a Pasteur pipette then transferred to a test tube before being brought to the vortex to homogenize well. The suspension thus obtained was filtered through a muslin sheet and diluted with distilled water containing 0.05% Tween 20 and 5% gelatin so as to obtain a final concentration of 106 conidia / ml using a Malassez slide. The plant material consisted of 60 in vitro plantlets of bananas of two varieties “Avlan” and “Sotounmon” (30 plants each) provided by the Niaouli Agronomic

Research Center (CRA-Niaouli), INRAB. The fungal material was composed of nine (9) isolates of *Fusarium oxysporum* and Nine (9) isolates of *Fusarium graminearum*.

The inoculation consisted of putting 20 ml of spore suspensions (106 spores / ml) of Fusarium isolates to the roots and leaves. The suspension was injected using a sterile syringe into two main roots and the main vein of three leaves per plant. These young plants were placed in a greenhouse using a Fischer block device for six (06) weeks. Young plants inoculated with distilled water were considered as controls. This experiment was repeated three times. The green and yellow leaves present on each cultivated banana plant were counted weekly during the six (06) weeks. The incidence and severity of the disease were determined after the percentage inoculation of plants that developed symptoms of internal and external wilt of *Fusarium* spp. by the sixth week, the coloring of the mature leaves and the condition of the root system of each young plant were noted. The search for necrosis was also made through longitudinal sections made in the rhizome of each infected young plant. The diagnosis of this disease was made at the level of the roots and leaves of infected young plants, according to the isolation method of Davet (1997) on PDA culture medium and identified according to the identification keys.

Symptom assessment

Symptoms of Fusarium wilt were rated using the following rating scale:
0 : healthy leaves
1 : Yellowing of the lower leaves
2 : Yellowing of all lower leaves and slight discoloration of younger leaves
3 : Developed stage of infection :Wilting of leaves
4 : Death of the plant.

The infection index was evaluated for each plant of each replicate, at each stage of growth according to the following formula (Carlier, 2002):

$$I = \frac{\sum nb}{(N-1)T} x\ 100\ (2)$$

Where:

I: Incidence of the disease

b : degree of scale

n : number of sheets for each degree of the scale

T : total number of leaves evaluated

Data analysis. The data collected during the evaluation of the various parameters were subjected to an analysis of variance (ANOVA with on factor) using the STATISTICA software version 7.1. In case a significant difference was observed, the means were compared using the Student-Newman-Keuls test at the 5% threshold in order to distinguish groups according to the mean values of the tested variables.

RESULTS

Distribution of Fusarium wilt in the Communes. The surveys carried out in the eight study areas (Missrété, Sakété, Adja-Ouèrè, Avrankou, Adjara, Ifangni, Tori and Allada) in 72 banana plantations (Table 1), revealed the presence of symptom of Fusarium observed on the leaves and manifested as yellowing and drying that progress from the base upwards. The yellowing was accompanied by sagging of the leaves at the level of the petiole or more generally towards the base of the midrib and hang down forming a “skirt” of dead foliage around the pseudo-stem (Fig 5). The symptoms differed to some extent according to the locality, the cultivar attacked and the growing conditions. The surveys carried out in the eight (08) communes of southern Benin made it possible to observe the characteristic symptoms of Fusarium wilt. The distribution of the disease varied from one locality to another. In the communes of Missrété, Sakété, Tori, Ifangni and Allada, surveys revealed that, in several banana plantations, the disease was present and caused significant damage. In contrast, in the Avrankou area, the disease was rarely observed and sometimes absent.

Table 1. Location, characteristics of the investigated sites and number of samples

Communes	Sites	Longitude	Latitude	Altitude (m)	Varieties	Number of samples
MISSRETE	Katagon 1	002 36’42.1”	06 36’12.4”	31	Avlan	30
	Katagon 2	002 36’01.5”	06 36’53.8”	36	Akpagbo	30
	Katagon 3	002 36’21.5”	06 37’08.5”	48	Planta	30
	Vakon 1	002 35’52.9”	06 31’54.5”	9	Sotunmon	30
	Vakon 2	002 35’38.9”	06 32’19.5”	30	Gbogui	30
	Vakon 3	002 34’18.7”	06 31’43.0”	39	Avlan	30
	Zoungbomè 1	002 34’04.9”	06 39’05.6”	73	Planta	30
	Zoungbomè 2	002 33’42.3”	06 39’39.9”	75	Planta	30
	Zoungbomè 3	002 33’58.1”	06 39’53.2”	78	Avlan	30
ADJARA	Adjara centre 1	002 39’53.8”	06 31’42.7”	36	Avlan	30
	Adjara centre 2	002 39’47.3”	06 31’46.0”	36	Goukokoé	30
	Adjara centre 3	002 39’54.3”	06 31’44.7”	32	Goukokoé	30
	Honvié 1	002 39’19.4”	06 31’02.0”	29	Goukokoé	30
	Honvié 2	002 39’18.8”	06 30’54.4”	37	Avlan	30
	Honvié 3	002 39’46.4‘’	06 30’46.7”	39	Avlan	30
	Malanhoui 1	002 40’26.7”	06 29’29.6”	12	Goukokoé	30
	Malanhoui 2	002 40’12.3”	06 29’30.6”	19	Avlan	30
	Malanhoui 3	002 40’16.6”	06 28’59.1”	18	Avlan	30
SAKETE	Sakété centre 1	002 38’24.5”	06 43’29.9”	69	Avlan	30
	Sakété centre 2	002 39’09.4”	06 43’40.2”	71	Ganhikkokoé	30
	Sakété centre 3	002 39’13.0”	06 41’20.1”	69	Avlan	30
	Takon 1	002 36’49.1”	06 39’43.5”	26	Ganhikkokoé	30
	Takon 2	002 36’57.8”	06 39’15.3”	38	Avlan	30
	Takon 3	002 36’41.2”	06 39’00.0”	39	Avlan	30
	Yoko 1	002 34’56.9”	06 42’34.4”	89	Avlan	30
	Yoko 2	002 35’41.1”	06 42’44.3”	84	Avlan	30
	Yoko 3	002 37’25.8”	06 43’14.9”	70	Avlan	30
ADJA-OUERE	Ikpinlè 1	002 37’07.6”	06 53’29.7”	119	Avlan	30
	Ikpinlè 2	002 37’28.7”	06 53’21.8”	129	Ganhikkokoé	30
	Ikpinlè 3	002 37’01.0”	06 54’31.5”	107	Planta	30
	Adja-ouèrè 1	002 36’36.7”	06 55’38.4”	131	Goukokoé	30
	Adja-ouèrè 2	002 36’20.5”	06 58’13.6”	132	PITA 3	30
	Adja-ouèrè 3	002 36’22.4”	06 59’44.6”	1O7	PITA 3	30
	Masse 1	002 35’16.7”	07 03’15.6”	53	Planta	30
	Masse 2	002 35’01.1”	07 05’05.3”	45	Avlan	30
	Masse 3	002 34’07.3”	07 05’53.5”	43	Avlan	30
IFANGNI	Tchaada 1	002 41’08.9”	06 35’17.9”	41	Avlan	30
	Tchaada 2	002 41’16.8”	06 35’14.3”	37	Avlan	30
	Tchaada 3	002 41’35.8”	06 34’46.6”	40	Avlan	30
	Daagbé 1	002 42’24.6”	06 34’19.3”	32	Avlan	30
	Daagbé 2	002 43’09.7”	06 34’35.0”	35	Avlan	30
	Daagbé 3	002 43’10.8”	06 34’32.1”	35	Avlan	30
	Banigbé 1	002 42’10.8”	06 38’04.9”	51	Avlan	30
	Banigbé 2	002 43’11.4”	06 38’04.5”	42	Avlan	30
	Banigbé 3	002 42’24.0”	06 38’51.5”	50	Avlan	30
AVRANKOU	Ouanho 1	002 39’08.4”	06 32’04.1”	29	Avlan	30
	Ouanho 2	002 39’16.5”	06 32’14.2”	33	Avlan	30
	Ouanho 3	002 39’33.3”	06 32’21.9”	11	Avlan	30

	Gbozounmè 1	002 40’26.8”	06 34’34.6”	44	Avlan	30
	Gbozounmè 2	002 40’24.0”	06 34’38.5”	43	Planta	30
	Gbozounmè 3	002 40’41.5”	06 34’52.1”	32	Avlan	30
	Sédjè 1	002 39’07.7”	06 33’04.4”	19	Planta	30
	Sédjè 2	002 39’36.2”	06 32’55.4”	29	Planta	30
	Sédjè 3	002 39’54.7”	06 32’59.4”	34	Planta	30
TORI	Gbégoudo	002 11’01.4”	06 34’50.0”	62	Avlan	30
	Goussa	002 10’70.3”	06 34’74.6”	72	Péripita	30
	Cada	002 11’20.2”	06 32’00.4”	52	CRBP755	30
ALLADA	Allada 1	002 08’60.9”	06 38’61.4”	95	50C	30
	Allada 2	002 08’49.6”	06 37’48.5”	92	Avlan	30
	Allada 3	002 08’69.0”	06 38’75.3”	98	Avlan	30
Total	1800					

Figure 5. External and internal symptoms characteristic of Fusarium wilt observed on banana plants. a: Banana field attacked by Fusarium wilt; b: Cross section of the stipe with necrosis at the periphery of the main axis; c: Uniform yellowing of mature and young leaves of an infected banana plant; d: Necrotic root system; e: Cross section of the stripe showing necrosis of the main axis; f: Dead banana plant

The results showed that the infection rate varied from 12.59 to 61.11% for all the plots studied. This rate, calculated as the ratio of diseased plants to all of bananas evaluated, varied between localities, and within localities. The locality of Avrankou had a low percentage (12.59%) of diseased plants compared to the other seven localities surveyed. The locality of Missrété had a higher incidence (61.11%) (Fig 6). The results indicated varied response: "Avlan" (63.30%), "Sotounmon" (42.86%), "Planta" (33.85%). The cultivars "Gbogui" (0%) and "Akpagbo" (0%) showed no symptoms of Fusarium in the 72 banana plantations surveyed (Fig 7). According to farmers, these cultivars were free from the typical symptoms of Fusarium.

Isolation and identification of Fusarium isolates from plant and soil. The results of the disease progression on infected banana plants are shown in Figure 5. All samples of infected roots and leaves revealed the presence of Fusarium.

The result of the disease incidence among the communities and varieties are presented in Figures 6 and 7. From the result it was observed that Missrete and Ifangni had the highest disease incidence of 60% while Avrankou had the lowest disease incidence of 10%. Also, from the result it was observed that Avlan variety had the highest disease incidence while Gbogui and Akpagbo had the lowest disease incidence.

The result of the isolation frequency per sample source and among communities are shown in Figures 8 and 9. From the result, it was observed that about 51.78% of the isolates were isolated from soil, 29.83% from the roots and 18.38% from the leaves. Statistical analyzes showed that these frequencies were significantly different. Also, the soil sample had the highest number of Fusarium.

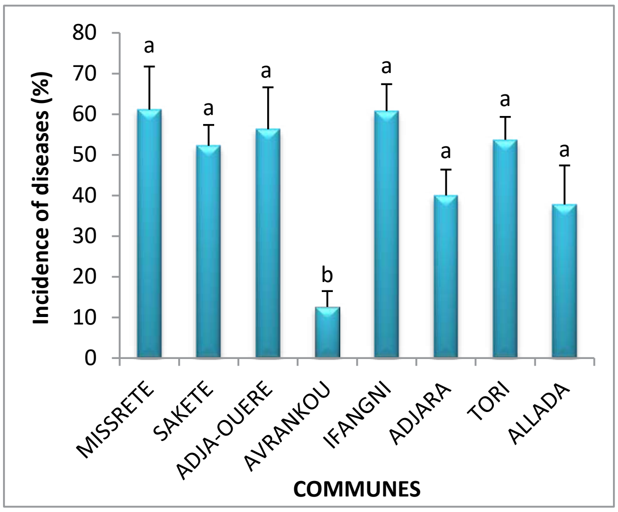


Fig. 6. Incidence of *Fusarium* wilt by locality

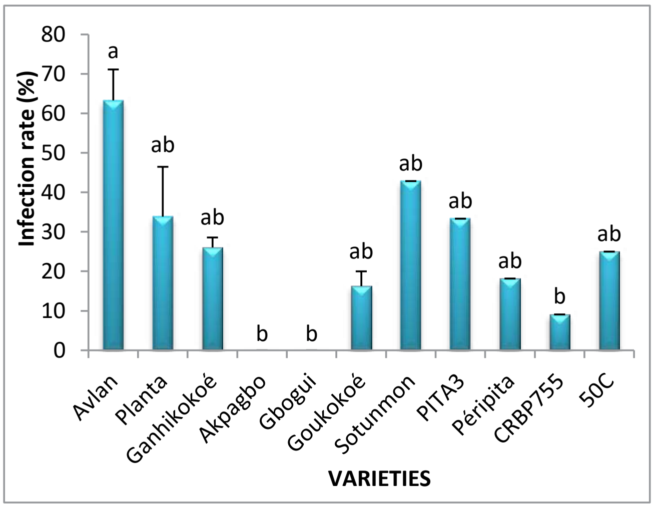


Fig. 7. Incidence of *Fusarium* wilt on infected banana cultivars

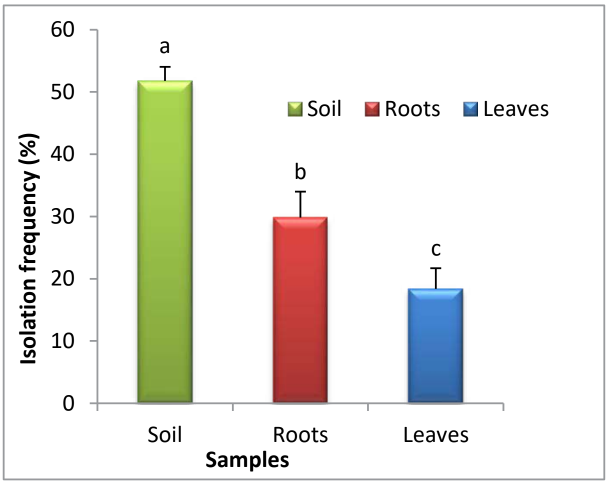


Fig. 8. Isolation frequencies of *Fusarium* spp. according to samples

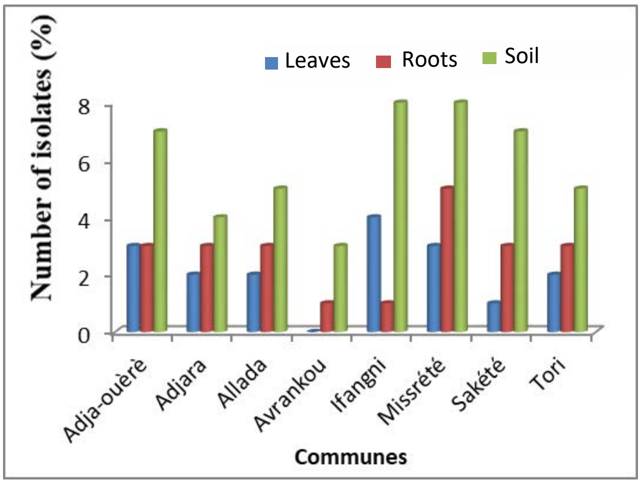


Fig. 9. Distribution of *Fusarium* spp. per locality sample

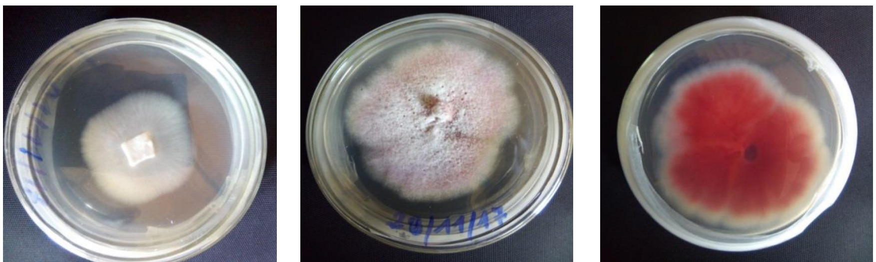
The appearance of the mycelium and the color of the colonies on PDA culture medium made it possible to classify the isolates into two homogeneous groups:

1. Group 1. Colonies of fluffy white color, fine, curly, showing a cottony, aerial and scanty mycelium at the periphery with a slow growth (8.6 cm in diameter in 9 days). The number of isolates carrying this type was 77 (Fig 10a).

2. Group 2. Colonies were salmon pink in color, showing abundant, redaerial mycelium upside down from the petri dish with rapid growth (8.2 cm in diameter in 6 days). The number of isolates carrying this type was 9 (Fig 10b, c).

Microscopic observations showed septate, branched and hyaline mycelium for all isolates. However, we noted the presence of a false head on the micro phialids which are of short in length. The micro conidia were very numerous, ovoid, unicellular with dimensions of the order of 1.2 - 4.8 µm. Macro conidia had an almost straight, thin shape with three to four partitions, a basal cell in the shape of a foot and a curved and tapered apical cell. They were abundant, spindle shaped and produced from phyalids on conidiophores. Similar to the density of macro conidia, chlamydospores were generally scarce, but sometimes numerous in some isolates, especially those isolated from soil. They had a globular shape with thick walls. They were formed of hyphae (Fig 11).

Pathogenicity test of Fusarium isolates. The pathogenicity experiment was performed in a greenhouse to test the effect of Fusarium spores on young potted banana plants. The onset of leaf symptoms was observed from the 10th day after inoculation. They were characterized by yellowing and chlorosis that initially appeared on older leaves, followed by general wilting and then wilting of the plant. The yellowing of the leaves began along the margin and progressed to the vein to reach the entire leaf surface and the leaf margins turned a grayish-brown color (Fig 12).



a b c

Fig. 10 . Morphotype of the fusarium thallus. **a:** white fluffy morphotype, thin; **b:** Morphotype salmonpink, showing a white, aerial and abundantmycelium; **c:** Red back of the salmonpink morphotype

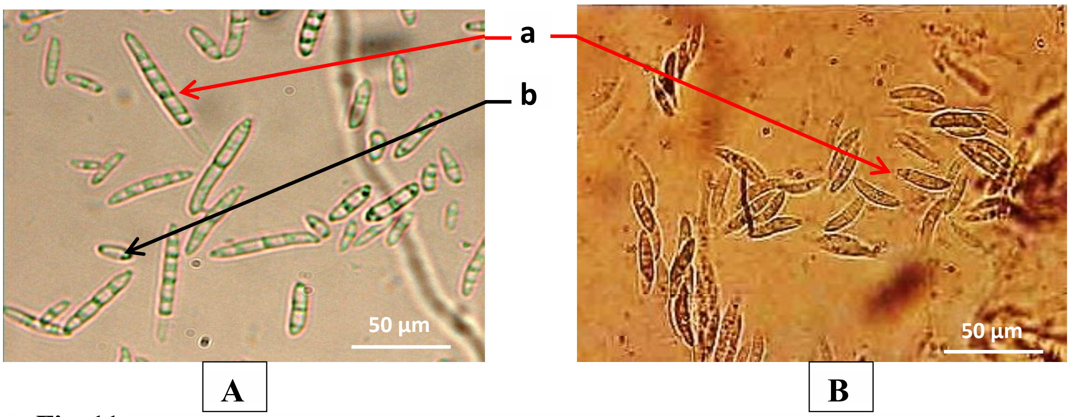


Fig. 11. Microscopic observation or micrograph of *Fusarium*. **A:** Microscopic observation of *Fusarium oxysporum* f. sp. cubense;**B:**microscopic observation of *Fusarium graminearum*; **a:**macroconidia; **b:**microconidia

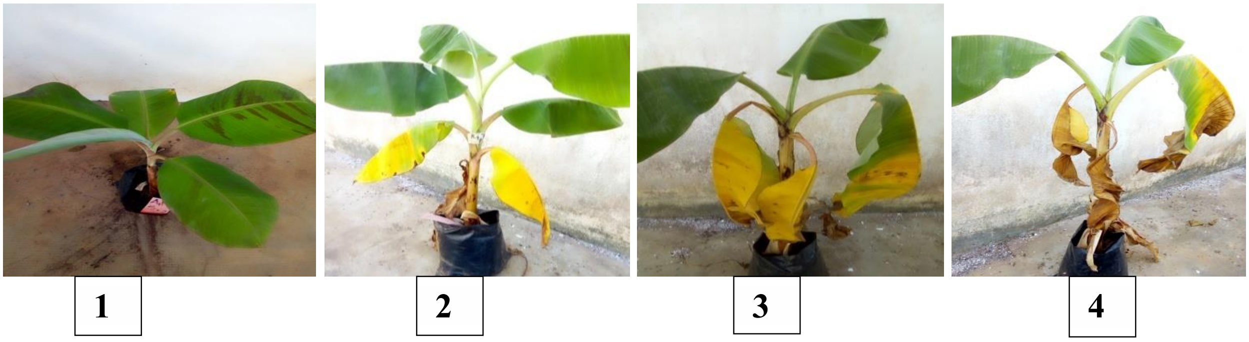
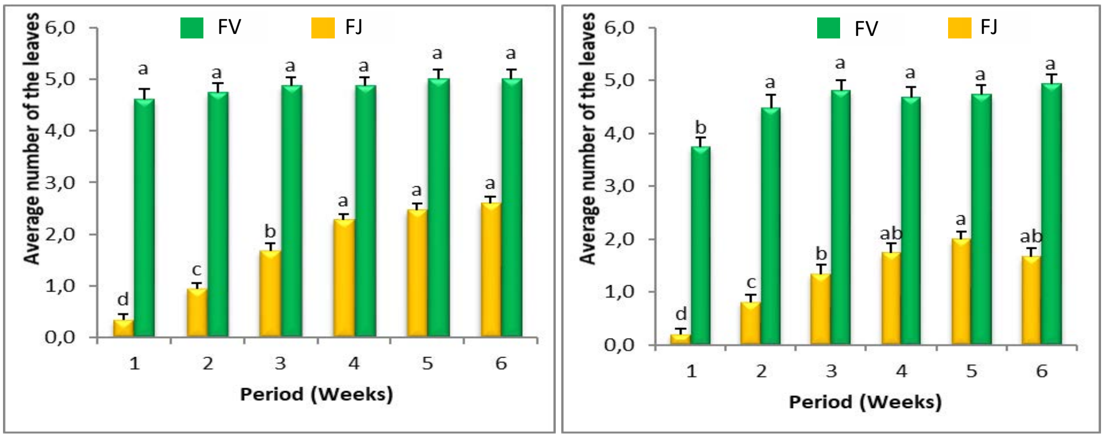


Fig. 12. *Fusarium* wilt rating scale based on external and internal symptoms in the Greenhouse. **1:** No symptoms; **2:** initial yellowing mainly on the lower leaves; **3:**Yellowing of all lower leaves with some discoloration of younger leaves; **4:**Withering and wilting of leaves

After three months, no early leaf yellowing was observed on the control plants (T). In contrast, all "Avlan" and "Sotounmon" banana plants inoculated with *Fusarium oxysporum* and *Fusarium graminearum* developed leaves which turned yellow early. Plants infected with these isolates also showed browning in the vascular tissue of the stipe. In the control plants, after six weeks and without the isolates, the average number of green leaves (NMFV) decreased from 4.60 to 5 for the variety "Avlan" and from 3.76 to 4.93 for "Sotounmon" and the average number of yellow leaves (NMFJ), from 0.33 to 2.60 and 0.20 to 2, respectively, for "Avlan" and "Sotounmon" (Fig 13 a and b). In young plants of the "Avlan" variety and in the presence of isolates, the evolution of NMFV and NMFJ varied with time.

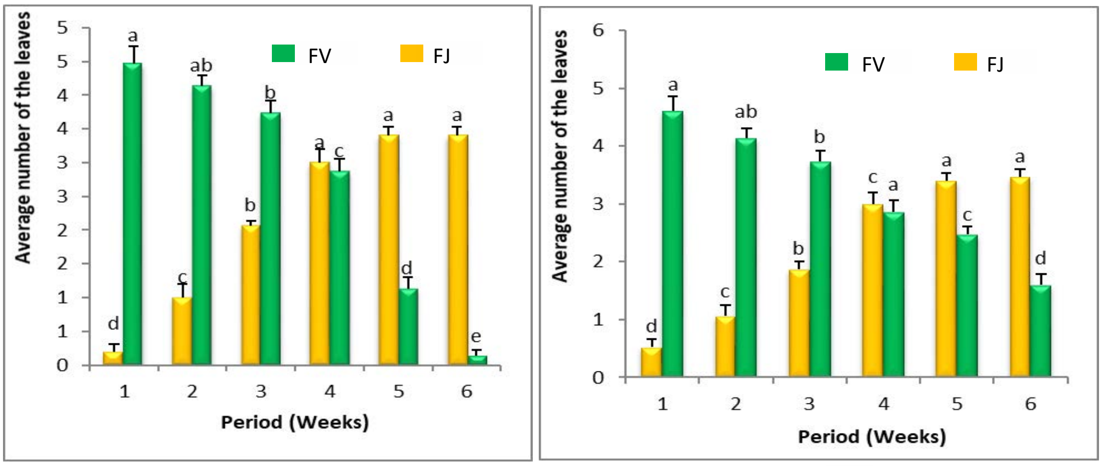
From the 1st to the 6th week, the NMFV gradually decreased from 4.46 to 0.13 while the NMFJ increased from 0.2 to 3.4 (Fig 14 a). In addition, in young plants of the variety "Sotounmon", the NMFV dropped from 4.6 to 1.6 while the NMFJ increased from 0.5 to 3.46 (Fig 14b). The analysis of the change in the average number of leaves after inoculation according to the Newman Keuls test revealed significant differences between the number of yellow leaves and the number of green leaves as a function of time.

The results shown in Fig 15 represent the severity of the disease on the leaves of the banana plants, six weeks after inoculation with the Fusarium species tested. For the "Avlan" variety, the severity of the disease was 86% for young plants treated with *Fusarium oxysporum* and 43.16% for those treated with *Fusarium graminearum*. For the variety "Sotounmon", the severity of the disease was 62.97% for the seedlings treated with *Fusarium oxysporum* and 36.50% for those treated with *Fusarium graminearum*. The results of analyzes showed that there was a significant difference between the severity of the two Fusarium species after inoculation.



a b

Fig. 13. Evolution of the average number of uninfected leaves as a function of time. **a:**Variety "Avlan"; **b:**Variety "Sotounmon" **FJ:** Yellow leaves ;**FV:** Green leaves



a b

Fig. 14. Evolution of the average number of infected leaves as a function of time. **a:**Variety "Avlan"; **b:**Variety "Sotounmon" **FJ :** Yellow leaves ;**FV :** Green leaves

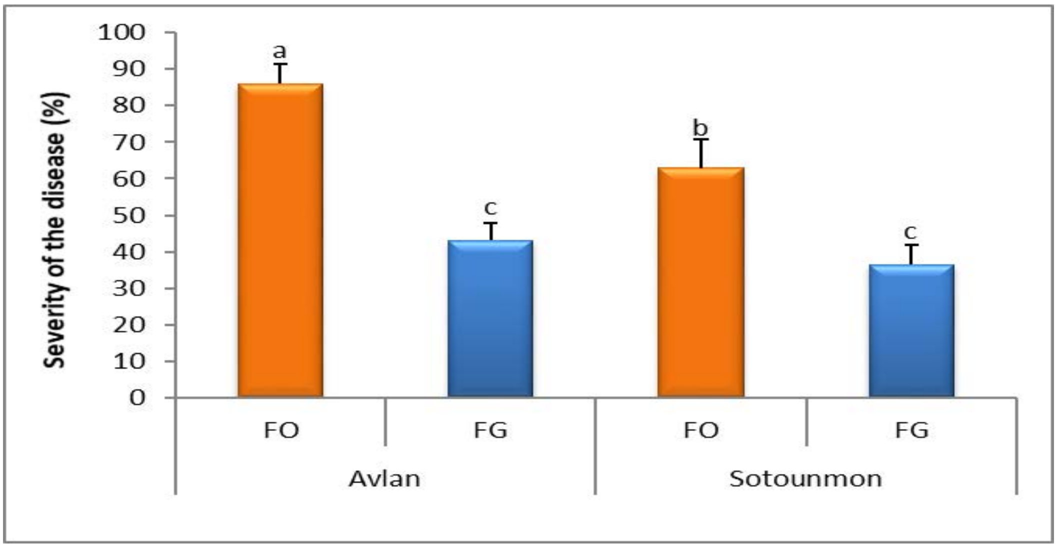


Fig 15. Disease severity (%) estimated on the leaves six weeks after inoculation of the banana plants with the two Fusarium species tested

DISCUSSION

Fusarium wilt of bananas is a disease with a very considerable negative impact in Benin. Its degree of attack directly affects the income of populations. Indeed, the external and internal symptoms of Fusarium wilt observed in the banana plantations of the eight localities surveyed were yellowing accompanied by wilting of the leaves and necrosis of the tissues. These symptoms are similar to those observed and described by Ploetz (2006) on banana caused by *Fusarium oxysporum* f. sp. *cubense*. The symptoms observed could be explained by the result of severe water stress due to the occlusion of the perforated plaques of the xylem vessels as well as by the combination of pathogenic activities such as the accumulation of mycelium, the production of toxins and / or the host defense response including the production of tylosis, gum, and vessel narrowing due to growth of parenchymal cells (Beckman, 1990). In addition, when the plant is alive, the pathogens confined to xylem cells and certain complementary cells, but once the plant dies, the pathogen invades the parenchyma and sporulates extensively (Ploetz and Pegg, 2000). Wilting could also result from obstruction of the root vascular system which is the entry route of *Fusarium oxysporum* into the plant, which explains the high rate of isolation of *Fusarium oxysporum* from soil and leaf roots (Li *et al*., 2017).

Results showed that *Fusarium oxysporum* isolated from roots was also found in soil and leaves at variable frequencies. These results corroborate those of Champion (1997) who showed that *Fusarium oxysporum* is widely spread Fusarium species in nature and behaves either as a parasite or as a saprophyte. The high isolation rate of this fungal species in the soils of the banana rhizosphere obtained in our results confirms that observed by Meddah *et al*. (2010) in the soils of banana plantations in Côte d'Ivoire. Indeed, this high incidence of the disease could be explained by the traditional method of banana cultivation, which disseminates the pathogen through the use of suckers from old plantations whose health status is unknown.

Characterization of isolates from each collection area showed a difference in conidial size and shape. Isolates with long or wide macroconidia were fusiform and microconidia were oval with one or two rounded extremities. This difference could be due to genetic diversity of *Fusarium* sp. isolates. Similar results were also obtained by Balali and Iranpoor (2006) who observed variability in the shape of Fusarium species. These authors said that, the difference would be due to genetic variability among Fusarium species. Macro-conidia with three partitions of isolated Fusarium isolates showed an average length which varied from 27 to 48.3 µm. This form is similar to that of *Fusarium oxysporum* f. sp. *cubense* (Foc), the causative agent of Fusarium wilt of banana which ranges from 27 to 55 µm, observed by Ploetz *et al*. (2000). The absence of symptoms on the cultivars of "Gbogui" and "Akpagbo" could be explained by the non-pathogenic nature of Fusarium on these two cultivars. This result was also observed by Nel *et al*. (2005) who demonstrated the presence of non-pathogenic isolates of *F. oxysporum* in the soils of the rhizosphere of banana plantations. However, in the presence of isolates of *F. oxysporum* and *F. graminearum* in the roots, infected bananas developed external and internal symptoms similar to those of Fusarium wilt six weeks after inoculation. These pathogens were also responsible for the development of root rots and the browning of the pseudo stem after inoculation. These results are in line with those of Hadi *et al*. (1987) who showed that the inoculation of banana roots with *F. oxysporum* f. sp. *cubense* had induced lesions after one week and that mechanical injury allowed the pathogen to colonize the cells of the cortex causing red dish brown lesions. David (1997) reported that *Fusarium oxysporum* and *Fusarium solani* are responsible for root rots.

The results obtained also made it possible to show that the number of conidia produced by the pathogen on the host can predict its pathogenicity. Rotem (1978) reported that the most infectious species are those capable of affecting more of the host tissue and allowing the inoculum to multiply. Isolates of *F. oxysporum* are significantly the most aggressive of both varieties compared to isolates of *Fusarium* *graminearum*. According to Pérez-Vicente and Dita (2014), a susceptible banana plant infected with Fusarium wilt will rarely recover. While recovery can occur, the growth is poor and the mother plant produces many infected suckers before it dies.

CONCLUSION

The soils of banana plantations infected with the fatal yellowing of banana leaves disease in southern Benin are heavily colonized by *Fusarium oxysporum*. The macroscopic and microscopic characters of isolates from this fungal species are similar to those of *Fusarium oxysporum* f. sp. *cubense*, the causative agent of Fusarium wilt of banana. Isolates of *Fusarium oxysporum* isolated from specimens infected with the disease were able to induce symptoms characteristic of Fusarium wilt in "Avlan", "Planta" and "Sotounmon" bananas. Pathogenicity assessment of the strains under controlled conditions revealed that they were pathogenic on the two varieties "Avlan" and "Sotounmon" and show different degrees of pathogenicity. The disease pressure is linked to cultivars and cropping systems. Cultivar type also influenced the incidence and severity of Fusarium wilt in banana.

ACKNOWLEDGMENTS

This study was supported by World Bank Group through the program "Centre d'Excellence Africain sur les Changements Climatiques, la Biodiversité et l'Agriculture Durable (CEA-CCBAD)" of Côte d'Ivoire. We thank Professor Kouamelan Essetchi Paul, for his support and Mr. Kochoni Innocent, for his contribution to all the work.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Aka, A.R., Kouassi, N.K., Agnéroh, T.A., Amoncho, N.A. et Sangaré, A. 2009. Distribution and incidence of cucumber mosaic (CMV) in industrial banana plantations in the south-east of Côte d'Ivoire. *Sciences Naturelles* 6 (2) : 171 183.

Arias, P., Dankers, C., Liu, P. et Pilkauskas, P. 2003. L'économie mondiale de la banane 1985-2002. Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO). 102pp.

Balali, G. R. and Iranpoor, M. 2006. Identification and genetic variation of fusarium species in Isfahan, iran, uning pectic zymogram technique. *Iranian Journal of Science and Technology, Transaction A* 30 (A1): 1-12 pp. DOI:10.22099/IJSTS.2006.2735;http://ijsts.shirazu.ac.ir/article_2735_400750634344d44fbf60844152a84f77.pdf

Beckman, C. H. 1990. Host responses to the pathogen: Fusarium Wilt of Banana. Ploetz, R.C. (Ed.). The American Society of Plant Pathology, St. Paul, MN.

Bouznad, Z. 1989. Contribution to the knowledge of the genus Ascochyta in legumes in Algeria. Biological, ultrastructure and cytochemical study of host-pathogen relationships in the *Ascochitapisi / Pisium sativum* couple. Doctoral thesis in Natural Sciences, Pierre Marie Curie University. 190 pp.

Carlier, J., De Waele, D. et Escalant, J.V. 2003. Evaluation globale de la résistance des bananiers à la fusariose, aux maladies foliaires causées par les *Mycosphaerella* sp. et aux nématodes. Evaluation de la performance (A. Vézina et C. Picq, eds). Guides techniques INIBAP 7. Réseau international pour l'amélioration de la banane et de la banane plantain, Montpellier, France. 62pp.

Carlier, J., De Waele, D. and Escalant, J.V. 2002. Overall assessment of the resistance of banana trees to Fusarium wilt, to leaf diseases caused by *Mycosphaerella* sp. and nematodes: In-depth evaluation. Vézina, A. and Picq, C. (Eds.). INIBAP technical guides 6. International network for the improvement of bananas and plantains, Montpellier, France. 63pp.

Carlier, J., De Waele, D. and Escalant, J.V., 2003. Overall assessment of the resistance of banana trees to Fusarium wilt, to leaf diseases caused by *Mycosphaerella* sp. and nematodes. Performance evaluation. Vézina, A. and Picq, C. (Eds). INIBAP technical guides 7. International network for the improvement of bananas and plantains, Montpellier, France. 62pp.

Champion, R. 1997. Identify the Mushrooms Transmitted by Seeds. INRA : Paris.

Daniells, J.W. 2009. Global banana disease management-getting serious with sustainability and food security. *Acta Hortic*. 828: 411–416.

Davet, P. and Roux, F. 1997. Detection and Isolation of Soil Fungi. INRA : Paris. 151-155pp.

David, J. R. 1997. Diseases of banana and plantain (Musa spp.). http://www.apsnet.org/online/common/names/banana.asp

Dhed'a, D. B., Moango M. A. et Swennen, R. 2011. La culture des bananiers et bananiers plantains en République Démocratique du Congo : support didactique. Edition Saint Paul Afrique, Kinshasa. 1-83pp. www.musalit.org/seeMore.php?id=13474

Do, N.V., Nguyen V.K. and Le H.H. 2001. Preliminary results of a virulence test of populations of *Fusarium oxysporum* f. sp. *cubense* (Foc) on different cultivars of banana trees in a greenhouse. *Info MUSA* 10 (2): 24-25.

FAOSTAT. 2017. Food and Agriculture Organization of the United Nations. Consult the 23/12/2017.

Gowen, S.R. 1994. Biological control of *Meloidogyne* spp. with *Pasteuria penetrans*. *EPPO Bulletin* 24 (2): 495-500.

Groenewald, S., Den Berg, N.V., Marasas, W.F.O. and Altus, V. 2006. The application of high through put AFLP's in assessing genetic diversity in *Fusarium oxysporum* f. sp. *cubense*. PhD Thesis, University of Pretoria, Pretoria, 78pp.

Hadi, M.A.A., Fadel, F. and Ghorab, A.I. 1987. Root rot of bananas and its control in Egypt. 161-171pp. In: Proceedings of the Conference of the Agricultural Development Research, Cairo, Egypt. http://www.apsnet.org/online/common/names/banana.asp.

Kangire, A. 1998. Fusarium wilt (Panama disease) of exotic bananas and wilt of East African highland bananas (Musa, AAA-EA) in Uganda. Thèse présentée pour l'obtention du diplôme de PhD. Department of Agriculture, Reading University. 304pp.

Kung'u, J.N. 1995. Fusarium wilt and other banana diseases in Kenya. *MUSA Info*. 4 (2): 14-16.

Lassoudière, A. 2007. The banana tree and its culture. Editions Quae. 384p.

Li, C., Shao, J., Wang, Y., Li, W., Guo, D., Yan, B., Xia, Y. and Peng, M. 2013. Analysis of banana transcriptome and profiles overall gene expression in banana roots in response to infection by race 1 and tropical race 4 of *Fusarium oxysporum* f. sp. *cubense*. *BMC Genomics* 14: 851.

Li, C., Yang, J., Li, W., Sun, J. and Peng, M. 2017. Direct root penetration and rhizome vascular colonization by *Fusarium oxysporum* f. sp. cubense are the Key Steps in the successful infection of Brazil Cavendish. *Plant Disease* 101 (12): 2073–2078.doi:10.1094/pdis-04-17-0467-re.

Meddah, N., Ouazzani, T.A. and Douira, A. 2010. Mycoflora associated with banana (*Musa accuminata* L.), Grande Naine variety, grown under glass in the Gharb region (Morocco). *Bulletin of the Scientific Institute* 32 (1): 1-11.

Nel, B., Steinberg, C., Labuschagne, N. and Viljoen, A. 2005. Isolation and characterization of non pathogenic *Fusarium oxysporum* isolates from rhizosphere of healthy 1514 banana plants. South Africa and INRACMSE. University of Burgundy France. *Plant Pathol*. 55 (2): 207 216.

Pérez-Vicente, L. and Dita, M. A. 2014. Technical Manual Senior Plant Pathologist, INISAV, Ministry of Agriculture, Cuba. Expert Consultant on Fusarium wilt disease of banana. Food and Agriculture Organization of the United Nations. Vol.4; 74pp.

Ploetz R.C and Pegg K.G. 2000. Fusarium wilt. pp. 143-159. In: Diseases of Banana, Abacá and Enset. Jones, D.R. (Ed.). CABI Publishing. 231-237.

Ploetz, R.C. 2006. Fusarium head blight is caused by several pathogens called *Fusarium oxysporum* f. sp. *cubense*. *Phytopathology* 96:

653 - 656.

Ploetz, R.C., Thomas, J. E. and Slabaugh, W.R. 2003. Diseases of banana and plantain. 109–112 pp. In: Ploetz, R.C. (Eds.). Diseases of Tropical Fruit Crops. Wallingford, UK: CAB International Publishing.

Rotem, J. 1978. Host and environmental influences on sporulation in vitro. *Ann. Rev. Phytopathology* 16: 83-101.

Van, E.S. 1999. Fruit Culture in the Tropics. 2nd edn. Agrodok: Paris.

Zambrano, A.Y., Martinez, G. and Gutierrez, Z. 2007. Identification of RAPD marker linked to resistance of Musa to *Fusarium oxysporum*. *Inci*. 32 (11): 775-779.

African Journal of Rural Development, Vol 7(1) January-April 2022: pp.53-67. ISSN 2415-2838

Evaluation of the Bull Scheme: An Open Nucleus Breeding System in the communal livestock farming areas of Namibia

L.N. MARIUS,[1] C. TOGAREPI[2] and I. SEIBEB[3]

[1]Directorate of Agricultural Research and Development, Ministry of Agriculture, Water and Land Reform, Private Bag 13184, Windhoek, Namibia

[2]Department of Agricultural Economics and Extension, University of Namibia, Ogongo Campus, Private Bag 5520, Oshakati, Namibia

[3]Directorate of Agricultural Research and Development, Ministry of Agriculture, Water and Land Reform, Private Bag 13184, Windhoek, Namibia

Corresponding Author: ctogarepi@unam.na; ctogarepi@gmail.com

ABSTRACT

The communal farmers in Namibia have been unsatisfied with the low prices received from the meat slaughter companies due to low carcass weight when selling their cattle. As a result, the Government prioritised increased quality livestock production through the implementation of the Bull Scheme in which breeding materials namely improved indigenous bulls (e.g Sanga) and exotic breeds were given to improve frame size. This study, therefore, assessed the impact of the "Bull Scheme" on the beneficiary farmers' livelihoods made through the provision of breeding male animals with a prime focus on the herds of the beneficiaries. A questionnaire-based cross-sectional survey was conducted on 105 beneficiaries and data was analysed using SPSS version 25.0. There was an overall increase in the herd/flock of beneficiaries comparing the number of animals before and after Scheme participation with an increase of 131%, 147%, and 67% for the bull recipients, ram recipients, and buck recipients respectively. There was also an increase in the number of cattle sold after the scheme by 43%, for the bull recipients ($t(83) = -2.445$, $p=0.017$), while incomes were reported to have increased. Regardless of initial training upon receiving the breeding males, farmers did not adjust their management practices upon the introduction of new breeding animals. Most beneficiaries indicated that they faced several challenges of expensive feed supplements, long-distance travelled in search of grazing and water which predisposed the scheme breeding males to poor conditions and even death of the animal. There is a need to train beneficiaries on record keeping and proper management as well as the goals of the project prior to project implementation.

Keywords: Beef production, beneficiary farmers, breeding males, challenges, farmer's perceptions, Namibia

RÉSUMÉ

Les éleveurs communautaires de Namibie sont insatisfaits des prix bas reçus des entreprises d'abattage de viande en raison du faible poids des carcasses lors de la vente de leurs bovins. Par conséquent, le gouvernement a donné la priorité à une production de bétail de qualité accrue grâce à la mise en œuvre du programme Bull, dans lequel des matériaux de reproduction, notamment des taureaux indigènes améliorés (par exemple, Sanga) et des races exotiques, ont été fournis pour améliorer la taille des animaux. Cette étude a donc évalué l'impact du "programme Bull" sur les moyens de subsistance des agriculteurs bénéficiaires grâce à la fourniture d'animaux mâles reproducteurs, en mettant l'accent sur les troupeaux des bénéficiaires. Une enquête transversale basée sur des questionnaires a été menée auprès de 105 bénéficiaires et les données ont été analysées à l'aide de la version 25.0 de SPSS. On a constaté une augmentation globale du troupeau des bénéficiaires en comparant le nombre

Cite as: Marius, L. N., Togarepi, C. and Seibeb, I. 2022. Evaluation of the bull scheme: An open nucleus breeding system in the communal livestock farming areas of Namibia. *African Journal of Rural Development* 7 (1): 53-67.

Recieved: 28 June 2021
Accepted: 31 December 2021
Published: 30 April 2022

d'animaux avant et après la participation au programme, avec une augmentation de 131 %, 147 % et 67 % pour les bénéficiaires de taureaux, de béliers et de boucs respectivement. On a également constaté une augmentation du nombre de bovins vendus après la mise en place du programme de 43 % pour les bénéficiaires de taureaux (t(83) = -2,445, p=0,017), tandis que les revenus auraient augmenté. Indépendamment de la formation initiale reçue lors de la réception des animaux reproducteurs, les agriculteurs n'ont pas ajusté leurs pratiques de gestion à l'introduction de nouveaux animaux reproducteurs. La plupart des bénéficiaires ont indiqué qu'ils rencontraient plusieurs défis liés au coût élevé des suppléments alimentaires, aux longs déplacements à la recherche de pâturages et d'eau, ce qui exposait les animaux reproducteurs du programme à des conditions précaires et même à la mort des animaux. Il est nécessaire de former les bénéficiaires à la tenue de registres et à une gestion appropriée, ainsi qu'aux objectifs du projet avant sa mise en œuvre.

Mots clés : Production de viande bovine, agriculteurs bénéficiaires, animaux reproducteurs, défis, perceptions des agriculteurs, Namibie

INTRODUCTION

The livestock sector is the single largest agricultural contributor to the Gross Domestic Product (GDP) of Namibia. The country has about 2.2 million cattle, 1.8 million goats, 2.5 million sheep, and a few pigs which all contribute 76% to the overall agricultural output value (Namibia Livestock Census, 2011; NDP4, 2012). About 80% of beef and mutton production is exported to South Africa and Europe which on average contributes between 10-15 % to the national income (Kruger and Lammerts-Imbuwa, 2008; Namibia Meat Board Report, 2011) depending on the amount of rainfall in a particular year. Amongst others, Government set priorities to increase livestock production, and development of the livestock sector particularly communal farming in the country (NDP4, 2012). The Ministry of Agriculture, Water and Land Reform (MAWLR) implemented the Bull Scheme program during the 2007/2008 financial year in which a total of 166 breeding males were distributed to communal livestock farmers; being 104 bulls, 36 goats, and 26 sheep. Similar programs were implemented earlier by the MeatBoard of Namibia (2003-2005), and later by GOPA (2010-2014).

The Bull Scheme in this study refers to the provision of livestock breeding materials directly to communal farmers. The communal farmers in Namibia have been unsatisfied with the low prices received at the meat slaughter companies due to low carcass weights when selling their cattle. As a result, the government prioritised increasing livestock production and the quality of animals through the implementation of the Bull Scheme. The breeding materials which were given were improved indigenous bulls (e.g. Sanga) and some exotic breeds to improve frame size. The main goal of the Bull Scheme project was to provide livestock breeding material to communal farmers thereby improving the productivity, and food security, creating and generating income through selling high-quality livestock; training farmers in various livestock management; strengthen the contact and relationship between the extension and farmers and encourage record-keeping of farm information. Breeding males distributed were bulls, rams, bucks, and a few boars, however, this study focuses on only the impact of the bulls, rams, and bucks. The most popular beef cattle breeds which were distributed to communal farmers through the Bull Scheme were; Brahman, Bonsmara, Simmentaler, Afrikaner, and the improved Sanga. The scheme was monitored by the extension officers and animal health technicians in the region. About 20% of total breeding males bred at government breeding stations were allocated annually to the communal farmers through the scheme.

The approach that was used in the scheme follows that of the open nucleus-breeding scheme (ONBS). Cunningham (1980) described an open nucleus-breeding scheme as a good strategy for genetic improvement in the absence of artificial insemination (AI) and record-keeping. ONBS is also the most appropriate for a subsistence production system. The breeding strategy used in this study follows that of an ONBS consisting of a three-tier pyramidal structure comprising the nucleus herd, commercial herd, and village herds. In this case, the nucleus herds were the livestock breeding research stations or farms, which produced a small number of best quality sires, on-farm tested, and were then distributed at a subsidized price to the owners of communal herds.

The Scheme was monitored by the agricultural extension officers together with animal health officers stationed in the regions by visiting the village herds. The monitoring process was carried out to assess both the adaptability and performance of the bulls. However, there is almost no performance recording of livestock in communal farming and therefore it has been difficult to determine the performance of crossbreds (Marius *et al.,* 2012, Marius *et al.,* 2021). However, the Namibia Livestock Identification and Trace-back System (NAMLITS) was therefore implemented by MAWLR to trace animals and control animal diseases in the fulfilment of the requirement of meat exports. Lack of animal performance recording has been known for a long to affect genetic improvement programs with negative results in the communal areas of most developing countries (Kahi *et al.,* 2003; Roessler *et al.,* 2008). Tada *et al*. (2012) reported that the absence of performance records, particularly of the indigenous communal breeds can lead to the undefined breeding season and uncontrolled mating. The consequences of uncontrolled mating are well documented and include, among others; the production of un-uniform animals, the presence of undesirable and genetic defects, and inbreeding depression (Scholtz *et al.,* 2008; Scholtz and Theunissen, 2010).

Crossbreeding has been reported to ensure rapid genetic progress with desired traits hence complimentarily of traits and exploit heterosis in animal performance (Imbayarwo-Chikosi, 2009). In as much as crossbreeding improves frame size and breed vigour, it may lead to the loss of indigenous animal genetic resources. The conservation of adapted indigenous cattle breeds in vivo such as breeding research stations, in vitro for example conservation of genetic material in liquid nitrogen, is supported by FAO (Wollny, 2003; FAO, 2007). In Namibia, cross-breeding with exotic breeds is common in communal livestock farming (Marius *et al.,* 2012). The adaptability of breeds becomes very important, especially in marginal semi-arid lands where grazing is limited and also with long, dry, and hot conditions which affect mostly exotic breeds but is suitable for indigenous breeds.

Introducing bulls to the communal areas help in introducing new genetic material. However, in recent studies, developing countries have been losing many indigenous livestock breeds as a result of farmers' preference for exotic breeds that are perceived to be more productive. In Botswana, the study by Nsoso and Morake (1999) did not recommend cross-breeding practice under the traditional farming system because of the unavailability of fences which leads to uncontrolled breeding. In Zambia, efforts to improve the productivity of indigenous cattle through crossbreeding with high-performing exotic breeds did not work very well because there was no provision of a continuous supply of the exotic breeds to the communal farmers (Simbaya, 2005).

To inform future projects, programming, and other interventions, it is imperative to assess the bull scheme in terms of its implementation (what worked and what did not work), outcomes, and impact on the beneficiaries' livelihoods. The study further assesses whether the project achieved its objectives or fell sort based on the outcomes. This study, therefore, sought to evaluate the impact of the bull scheme project on the beneficiaries.

MATERIALS AND METHOD

Study area. The Scheme distributed breeding male animals to communal areas within the 13 regions (excluding the Khomas region) (Figure 1) and villages were irrelevant to the list. The areas fall under ecological zones defined as arid to semi-arid and desert to coastal along the Atlantic Ocean. In general, rainfall is highly variable, from less than 20mm in the western coastal zones to 700 mm north-east of the Zambezi strip (Mendelssohn, 2006). Temperature ranges between 3 and 39° C, indicating high temperature, high evaporation, and surface runoff, while groundwater recharge is very minimal (Mendelssohn, 2006). Furthermore, the country, of late experienced frequent droughts coupled with temporal and spatial unequal rainfall distribution. The livestock production system is characterised mainly by extensive grazing across the country with sheep and goats dominating the southern part of the country, while cattle and crops are in wetter areas mainly the north-central and north-east.

Sampling and data collection . The 'Bull Scheme' in this study refers to the provision of livestock breeding materials directly to communal farmers in all the regions of Namibia excluding Khomas region. The Scheme was implemented by MAWLR from 2007 to 2014. A total of 166 breeding males were distributed to communal livestock farmers; being 104 bulls, 36 goats, and 26 sheep.

A purposive sampling design was used in the study because only beneficiaries were allowed to participate in the survey using the beneficiaries list. The research design comprised a quantitative and qualitative approach in a questionnaire to capture qualitative and quantitative information. Data were collected using a structured questionnaire administered through face-to-face interviews with the Scheme beneficiaries. The data were collected between October 2013 and February 2014. The sampling frame consisted of all beneficiaries, however, the target sample size was 50% of beneficiaries (83) since homogeneity of the target population was assumed. A total of a hundred and five (105) respondents were interviewed representing 63% of all beneficiaries. Some of the questions that were asked in the questionnaire included: the number of animals before and after the scheme, number of livestock sold before and after the scheme, improvement in income after the scheme, improvement in weight of livestock sold after the scheme, fate of the breeding males and beneficiaries' perception of the scheme among others.

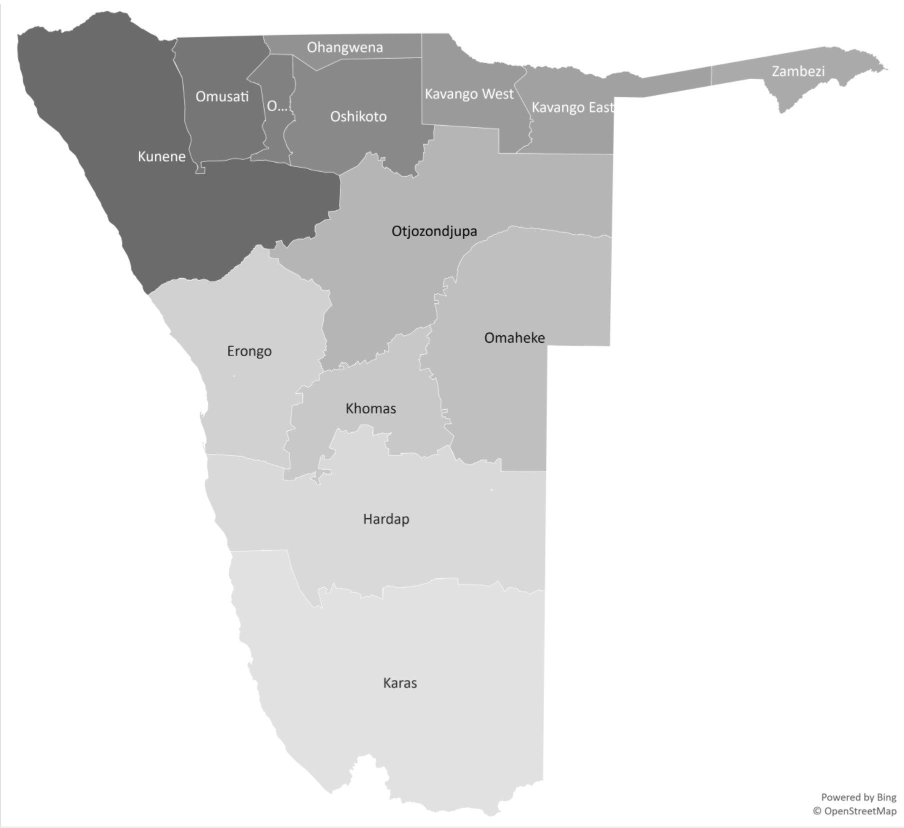


Figure 1. The map of Namibia showing the fourteen (14) regions

In addition, the approach used for assessment was based on Radhakrishna's (2001) model for evaluating agricultural and extension projects. The model posits three evaluation questions relating to (i) problem diagnosis and objectives that address the problem, (ii) the desired situation, and (iii) what the project actually achieved. This model framework guided the approach of this study.

Data analyses. Data were analysed using descriptive statistics (frequencies, means), graphical techniques (graphs), and a paired sample T-test to compare the number of animals kept and sold before and after the scheme using SPSS version 25 for Windows.

RESULTS

The demographic information of the beneficiaries in the Scheme is shown in Table 1. Data were collected and the percentage of beneficiaries with breeding males, on sex, age, marital status, level of education, and sources of income. Out of the 105 beneficiaries interviewed, 78.1 % received a bull, 12.4 % a buck, and 9.5 % a ram for breeding purposes. Most of the beneficiaries interviewed were married (71.4 %), males (84.8 %) aged 60 and above (38.1 %), who had at least a secondary education (39 %), and very few with no education background (16.2 %). Beneficiaries that were interviewed were mostly those whose incomes were drawn from farming (41%), however, 24.8 % indicated that they were permanently employed while others were pensioners (15.2 %). The majority of beneficiaries interviewed also had farm income between N$ 5001-10 000 (23.8 %) and N$ 50001-100 000 (21.9 %) per year, whereas, 31.4 % earned income from non-farm businesses and 21 % of farmers had no information on their farm incomes.

Table 1. Demographic information of the beneficiaries in the Scheme

Variable		Total (%)
Breeding male	Bull	82 (78.1)
	Ram	10 (9.5)
	Buck	13 (12.4)
Sex	Female	16 (15.2)
	Male	89 (84.8)
Age (years)	20-30	4 (3.8)
	31-40	9 (8.6)
	41-50	14 (13.3)
	51-60	35 (33.3)
	61+	40 (38.1)
	Do not know	3 (2.9)
Marital status	Single	23 (21.9)
	Married	75 (71.4)
	Widow/er	6 (5.7)
	No answer	1 (1.0)
Level of Education	Primary(grade 0-7)	29 (27.6)
	Secondary (grade 8-12)	41 (39.0)
	Tertiary(college and university)	18 (17.1)
	No education/Literacy	17 (16.2)
Major source of income	Farming	43 (41.0)
	Permanent employment	26 (24.8)

	Pensioner	16 (15.2)
	Other business	7 (6.7)
	Farming and permanent employment	3 (2.9)
	Farming and pensioner	6 (5.7)
	Farming and other business	1 (1.0)
	Pension and other business	2 (1.9)
	No answer	1 (1.0)
Farm grouped income/ year	500-1000	12 (11.4)
(N$)	1001-5000	14 (13.3)
	5001-10000	25 (23.8)
	50001-100000	23 (21.9)
	50001-100000	12 (11.4)
	100000+	3 (2.9)
	No answer	16 (15.2)
Non-farm grouped income/year(N$)	500-1000	3 (2.9)
	1001-5000	11 (10.5)
	5001-10000	33 (31.4)
	50001-100000	16 (15.2)
	50001-100000	12 (11.4)
	100000+	8 (7.6)
	No answer	22 (21.0)

1 USD = N$ 14.67, the number in brackets represents the percentage

Performance progress in the Scheme. Table 2 shows the performance progress in the Scheme from October 2008 to February 2014. The mean number of persons per household with a bull, ram, or buck were (10±7), (10±7), and (8±7) respectively. The results indicated a lot of variability in farm income per year of N$24045±43315, N$23500±29640, and N$8462±13611 for the bull, ram, and buck respectively. The non-farm income per year of N$50123±148890, 25840±32940, and N$8117±12803 for the bull, ram, and buck respectively. Beneficiaries reported an increase in the mean number of herd/flock in the scheme of bull (7±14 to 10±19) and ram (14±15 to 13±14) which is an increase of 115% and the bull and ram were kept in the herd for 3 years on average. Herd sizes before and after the scheme were significantly different with $t(83)=-.847$, $p=0.000$, flock size for those that received rams and bucks were significantly different with $t(9)=-3.202$, $p=0.011$ and $t(12)=-2.829$, $p=0.015$ respectively (Table 3). The number of animals sold by recipients of bulls slightly increased from 7.2±13.65 to 10.2±18.66, $t(83)=-2.445$, $p=0.017$ which represents approximately 11.8% increase in the number of livestock sold, while there was no significant difference for those that received a ram or a buck.

Table 2. Performance progress in the scheme from October 2008 to February 2014

	Bull (N=84)		Ram (N=10)		Buck (N=13)	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Age of beneficiary (years)	55	18	49	18	54	13
Household size	10	7	10	7	8	7
Farm income from livestock per year (N$)	24045	43315	23500	29640	8462	13611
Non-farm income/salary/wage per year (N$)	50123	148890	25840	32940	8117	12803
Total number of Herd/ Flock before scheme	35	71	19	19	33	38
Total number of Herd/ Flock after Scheme	81	105	47	20	55	48
Number of years of bull/ram/buck spent in the herd/flock	4	3	2	2	3	2
Number of animals sold per year before the scheme started	7	14	14	15	9	9
Number of animals sold per year as a member of the scheme	10	19	13	14	9	9

There was a significant difference in the herd size of farmers who received a bull before the scheme (34.9 ± 71.13) and the herd size after joining the scheme for at least five years (80.9±105.15), t(83)=-4.847, p= 0.000, while the flock size of farmers that received a ram and those who received a buck were significantly different before joining the scheme (19.1±18.96) and after joining the scheme 46.7±20.16, t(9)=-3.202, p=0.011 and 32.8±38.12 before and 55.5±47.7, t(12)=-2.829, p= 0.015, respectively. In addition, the number of cattle sold before joining the scheme was significantly different (7.2±13.65) from the number of cattle sold at least five years after the farmer had joined the scheme (10.2±18.66), t(83), =-2.445, p=0.017, while there was no significant difference in the number of goats and sheep sold for those who received a ram or a buck (Tables 3).

Table 3. Descriptive statistics and paired samples t-test statistics for the total number of livestock owned and sold before and after joining the scheme

	Breeding animal received	Number of animals	N	Mean	Std. dev	Std. Error Mean	t	df	Sig. (2-tailed)
Number of animals kept	Bull	Total herd size before the scheme	84	34.9	71.13	7.76	-4.847	83	0.000
		Total herd size after the scheme	84	80.9	105.15	11.47			
	Ram	Total flock size before the scheme	10	19.1	18.96	6.00	-3.202	9	0.011
		Total flock size after the scheme	10	46.7	20.16	6.37			
	Buck	Total flock size before the scheme	13	32.8	38.12	10.57	-2.829	12	0.015
		Total flock size after the scheme	13	55.5	47.54	13.18			
Number of animals sold	Bull	Total number of cattle sold before the scheme	84	7.2	13.65	1.49	-2.445	83	0.017
		Total number of animals sold after the scheme	84	10.2	18.66	2.04			
	Ram	Total number sheep sold before the scheme	10	13.5	14.62	4.62	0.044	9	0.966
		Total number of the sheep sold after the scheme	10	13.3	13.90	4.39			
	Buck	Total number of goats sold before the scheme	13	8.6	8.54	2.37	-0.113	12	0.912
		Total number of goats after the scheme	13	8.8	8.61	2.39			

Figure 2 shows the proportion of Scheme breeding males which were still available and those that were no longer available in the scheme. Beneficiaries were asked to indicate whether the Scheme bull, ram, or buck was still available in the herd/flock. The results showed that 46 % of bulls, 60 % of rams, and 39 % of bucks given by the Scheme were still available at the time of the survey.

Beneficiaries gave various reasons for the fate of the Scheme animal (Figure 3) mainly death (24% of bull beneficiaries, 40% of ram beneficiaries, 46% of buck beneficiaries) or sold/culled (24% of bull beneficiaries and 15% of buck beneficiaries) or other fate (7% of bull beneficiaries).

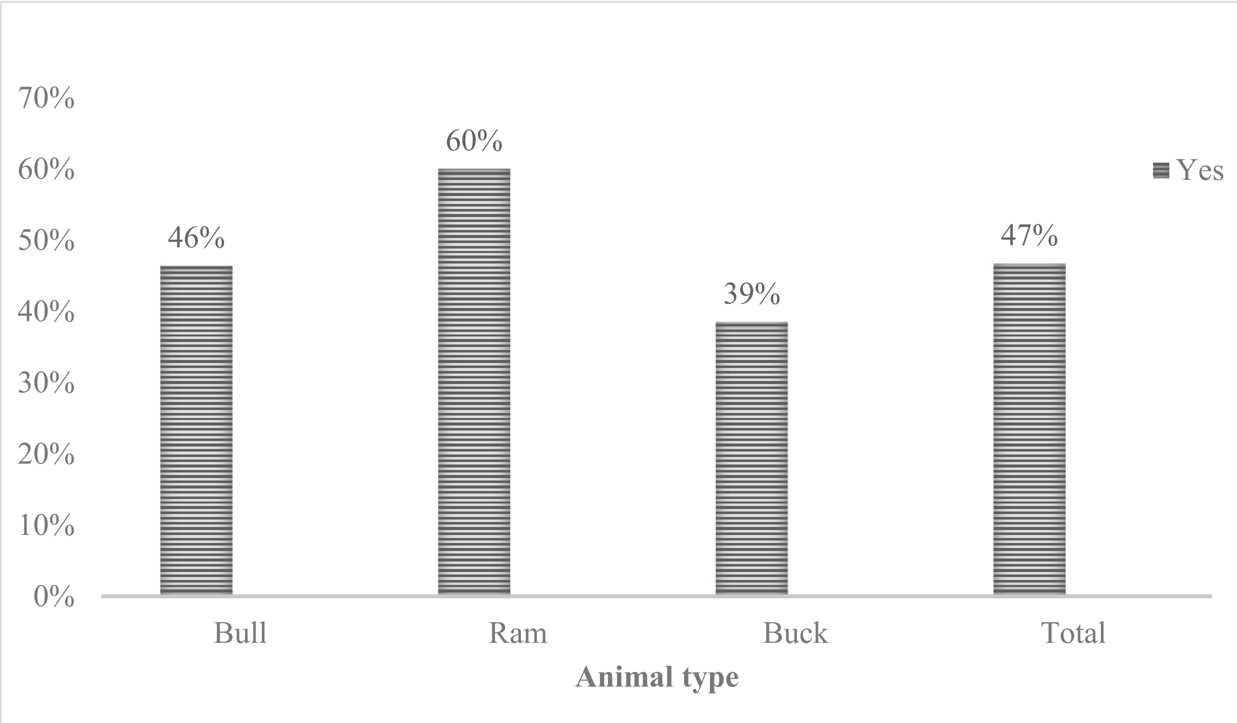


Figure 2. Proportion of breeding males of the Scheme which were available after at least five years from the start of the scheme

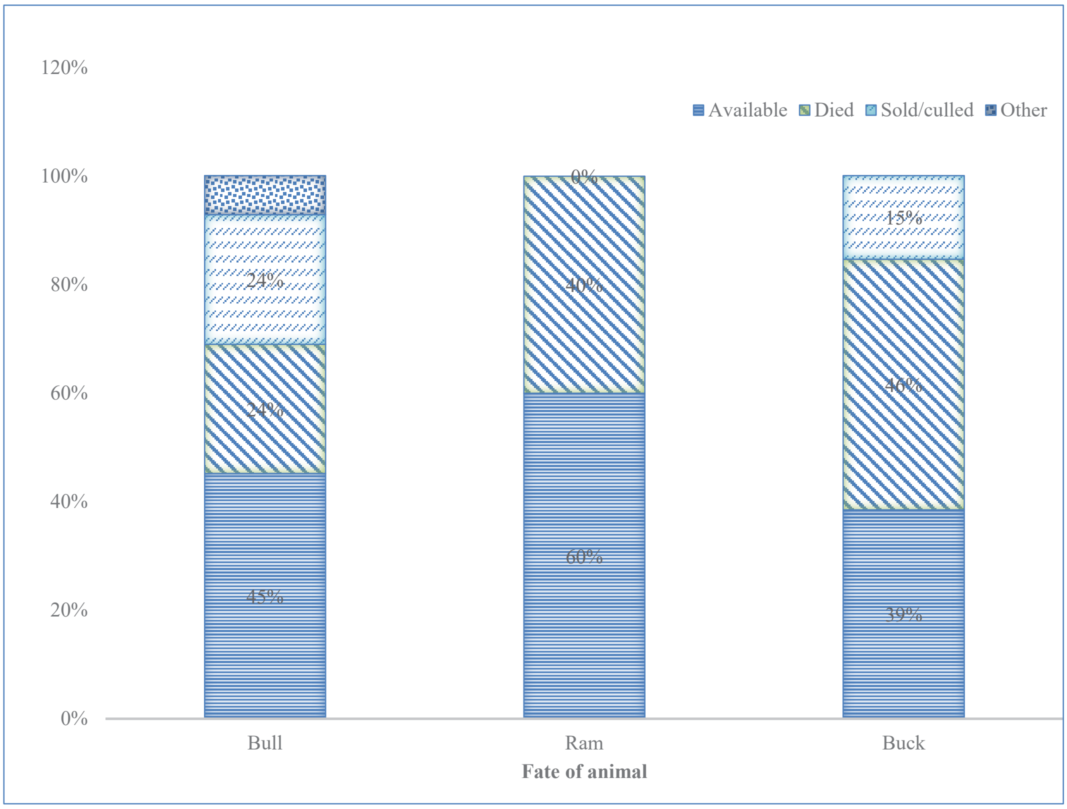


Figure 3. Fate of breeding animals given to farmers after five years (other in the figure represents animals castrated, lost or returned to the scheme)

In figure 4, animals that were sold after the scheme had improved weight and better price per animal. Farmers were asked if they were able to sell animals at a better price per weight per animal. Over 80% of beneficiaries indicated that they sold animals with better weight as compared to before the Scheme. The results further indicate that farm income improved over the period of five years of the scheme with an average of 53%. Respondents who received bulls (55%) had the most improvement in income while the ones who received bucks (46%) had the least improvement.

The respondents who sold their livestock used mostly auctions and informal markets (figure 5). Most of the farmers who received rams (70%) and bucks (46.2%) sold through auctions while those who received bulls preferred the informal marketing channel (37%). There were very few farmers in the scheme who did not sell their livestock (12%).

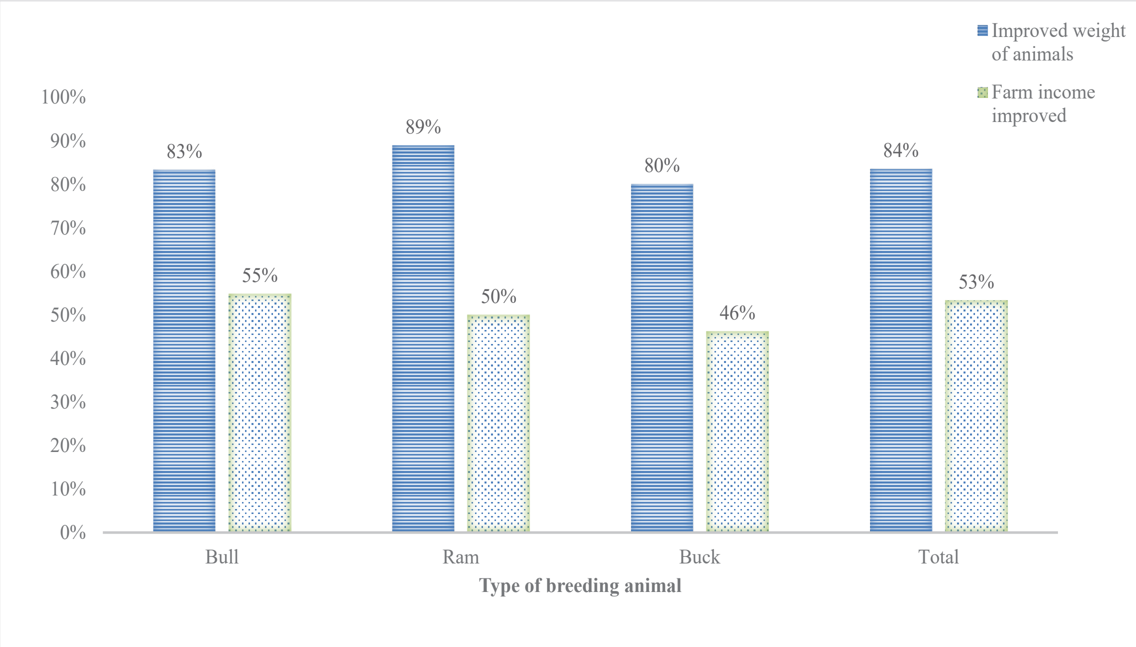


Figure 4. Improvement in weight of animals sold and improvement in income due to the scheme

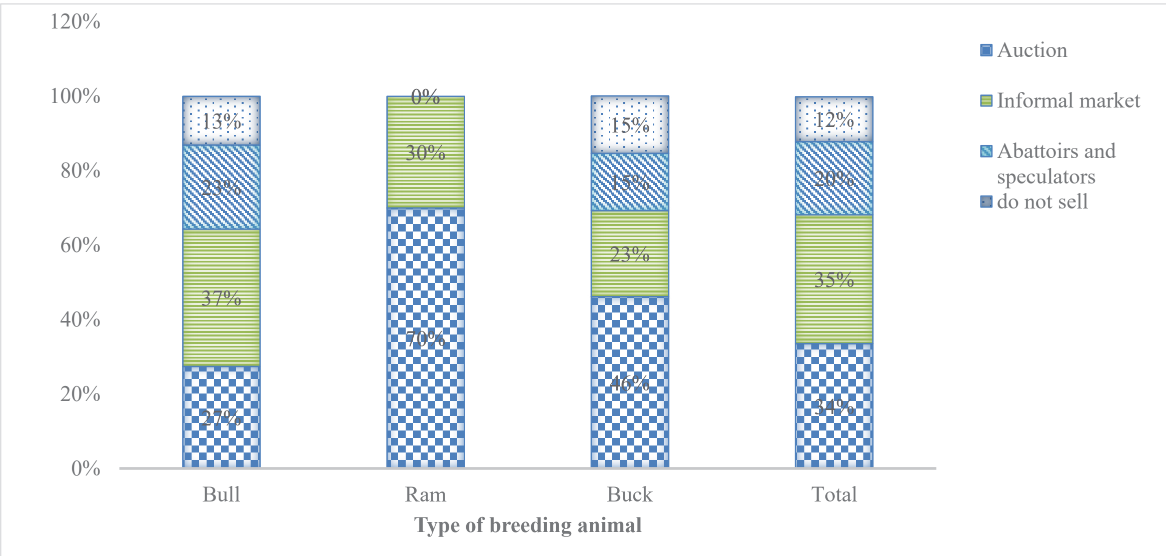


Figure 5. Marketing channel used by farmers of the scheme

Farmers' perceptions of the Scheme are shown in Table 4. About 28.6 % of farmers felt that the number of beneficiaries should be increased, followed by 27.6 % of beneficiaries who require more training in on-farm management. Other beneficiaries indicated that female breeding animals (15.2 %) should be added to the Scheme. There were a number of challenges that predisposed the herd improvement in the communal areas such as the frequent occurrence of drought that impacted negatively on fodder and grazing, poor farm management (i.e. disease control, feed supplementation, and record-keeping), lack of infrastructure i.e. fences, poor marketing channels and lack of transport to auction facilities.

Figure 6 indicates the process flow application of the evaluation model proposed by Radhakrishna (2001). Overall, the analysis shows that most farmers had positive outcomes as shown by an increase in the herd size, increase in sales as well as income from livestock sales. This was achieved despite challenges faced with deaths of breeding males and limited change in record keeping. Poor record keeping also made it difficult to assess some of the indicators for evaluation as some records were non-existent.

Table 4. Farmers' perceptions of the Scheme

	Frequency (%)			
	Bull(N=130)	Ram (N=12)	Buck (N=15)	Total
Increase number of beneficiaries	21 (19.6)			
	2 (1.9)	7 (6.5)	30 (28)	
Provide more breed types	10 (9.3)	1 (0.9)	0 (0.0)	11 (10.3)
Provide adapted bulls/ rams/buck	8 (7.5)	0 (0)	1(0.9)	9 (8.4)
Provide female animals	10 (9.3)	3 (2.8)	3 (2.8)	16 (15)
Provide every 2 to 3 years	10 (9.3)	1 (0.9)	1 (0.9)	12 (11.2)
Provide tested bulls/ rams/buck	3 (2.8)	0(0.0)	0 (0.0)	3 (2.8)
Provide training on management	27 (25.2)	1 (0.9)	1 (0.9)	29 (27.1)
Provide free marketing	1 (0.9)	1 (0.9)	0 (0.0)	2 (1.9)
Improve infrastructure	5 (4.7)	0 (0.0)	0 (0.0)	5 (4.7)
Provide transport for breeding animals	4 (3.7)	0 (0.0)	0 (0.0)	4 (3.7)
Provide feed supplements and subsidy on grazing	11 (10.3)	0 (0.0)	1 (0.9)	12 (11.2)
Increase frequency of visits	5 (4.7)	1 (0.9)	0 (0.0)	6 (5.6)
No problem with the scheme	9 (8.4)	1 (0.9)	1 (0.9)	11 (10.3)
Repeat/give beneficiaries again	4 (3.7)	1 (0.9)	0 (0.0)	5 (4.7)
Provide bull/ram/buck before the rains	2 (1.9)	0 (0.0)	0 (0.0)	2 (1.9)

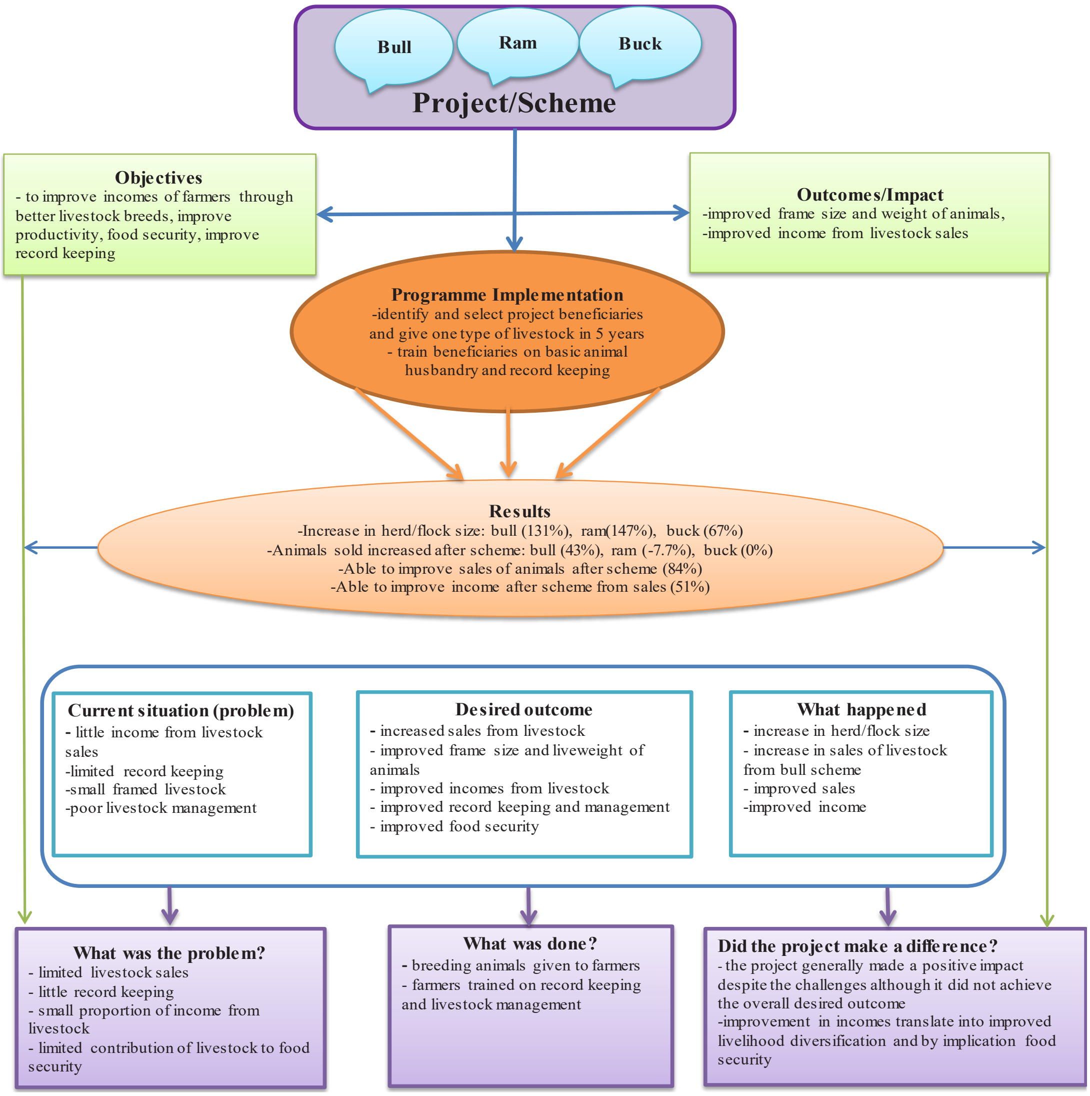


Figure 6. The evaluation results using the evaluation framework by Radhakrishna (2001) on the Scheme project

DISCUSSION

The majority of the Scheme beneficiaries that were interviewed consisted of individuals aged 60 years and above. Most households were male-headed, retired elderly men, whose incomes were drawn from agricultural farming and needed to support large families. Chepape *et al*. (2011) and Togarepi *et al*. (2016) reported similar gender, and age groups, and that pensioners (older people) were more readily available for farming compared to young farmers.

Livestock was marketed using either the formal or informal marketing channels or both with auctions used the most by those who received small stock while those who received bulls preferred the informal markets. Similar findings were reported by Thomas *et al*. (2014) on marketing channels used by communal farmers. However, for cattle, it seems it was more lucrative to sell informally as higher prices are negotiable compared to formal markets that have fixed prices. There was an increase in the number of animals in the herds which may have resulted in improved incomes of farmers after the scheme participation. Although the livestock numbers increased by 115% after the scheme, the number of sales only increased by 11.8% which indicates that most farmers in rural areas do not keep livestock for marketing purposes but for other reasons such as status and traditional and cultural reasons with sales only done when the need for cash arises. However, distance travelled to auction kraals, transport, poor market information, and the presence of the veterinary cordon fence were viewed as limiting to the success of livestock marketing in communal areas. These factors were also stated in the study of Marius *et al*. (2012) and Togarepi *et al*. (2016). Beneficiaries with sheep and goat breeding males indicated that it was difficult to notice an improvement in their flocks. Moreover, the results indicate a very high proportion of deaths (24%, 40%, 46%) among the breeding animals with bulls, rams and bucks respectively, which may indicate poor animal management practices and possibly effects of drought or disregard of the objectives of the scheme. The reason could be attributed to the lack of weight recording of animals at birth or weaning even at the market. Poor performance data recording and trait identification in communal livestock farming were also observed which concurs with the work of Roessler *et al*. (2008).

About 47.6 % of breeding males were still available at the time of the assessment; however, there was significant high demand for more breeding males as they were shared amongst the communities. Beneficiaries also indicated the need for training in farm management suggesting improvement in the Scheme regarding this aspect. Other concerns reported simply implied that the purpose of the Scheme and its implementation measures were not well understood (Table 4) by the beneficiaries. For example, beneficiaries were encouraged to remove or castrate existing breeding males in their herds, which was rarely the case. This caused fighting and injuries leading to ineffective breeding, death, or loss of the Scheme animals. Previous researchers working in communal livestock areas highlighted poor management practices and uncontrolled breeding (Nsoso and Morake (1999). In as much as trying to solve the problem of low carcass weights and improve prices, other problems may be introduced through crossbreeding for example loss of indigenous animal genetic resources.

CONCLUSIONS

The scheme was successful to an extent and had a positive impact on the farmers generally given that farmers could sell more animals at better prices than before the scheme and that herd size increased with better weight at weaning. Farmers who received rams and buck did not show improvement in numbers sold and this requires further investigation to ascertain the reasons for this. Overall, farmers that received bulls seemed to perform better in the scheme. Management practices improved to some extent, however, many farmers did not keep proper or sufficient records making it difficult to assess other parameters of the scheme. There remained some challenges that were alluded to by the beneficiaries such as adaptation of animals to the environment and inadequate feed/grazing that might have limited the success of the scheme. Despite the increase in herd and flock size that was achieved, there was a high death rate of the breeding animals especially among the rams and bucks given. In addition, schemes such as these have the potential to contribute to farm incomes and the diversification of livelihoods of communal farmers with proper planning, training, monitoring and evaluation of the schemes.

RECOMMENDATIONS

Many farmers want the “Bull scheme” to continue, however, stricter monitoring is required to enable the Scheme administrators to have all the information that is required through records. Reporting mechanisms need to be improved to have up-to-date information on the Scheme. There is also a need to carry out follow-up training to capacitate farmers not only on record-keeping but on marketing and business management principles for the farmers to appreciate their breeding stock as assets that have the potential to generate more income. Future schemes of similar nature will require extensive awareness and education campaigns to improve the potential for success and achievement of scheme goals. Regular monitoring and evaluation of schemes need to be done to ensure prompt response to problems such as high death rates among the breeding stock. This evaluation was the first since the Scheme was implemented, therefore future follow-up interviews with beneficiaries are recommended. There is a need to do a cost-benefit analysis of the scheme before a similar scheme can be resumed.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the provision of breeding male livestock to communal farmers through the "Bull Scheme" and funding from the Ministry of Agriculture, Water and Land Reform in Namibia.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Chepape, R.M., Mbatha, K.R. and Luseba, D. 2011. Local use and knowledge validation of fodder trees and shrubs browsed by livestock in Bushbuckridge area in South Africa. *Livestock Research for Rural Development* 23: 1-11. Available online at: http://www.lrrd.org/lrrd23/6/chep23132.htm.

Cunningham, E.P. 1980. In: Methods for Recording, Evaluation, and Selection in Adverse Environments. FAO/UNEP Technical Consultation on Animal Genetic Resources, Conservation, and Management, Rome, 12.

Food and Agricultural Organization (FAO). 2007. The State of the World's Animal Genetic Resources for Food and Agriculture-in brief, edited by Dafydd Pilling and Barbara Rischkowsky. Rome. Italy

Imbayarwo-Chikosi, V. 2009. Dairy Cattle Genetics and Breeding. ICART Dairy Science and Technology Module. University of Zimbabwe, Department of Animal Science, Mt. Pleasant, Harare, Zimbabwe.

Kahi, A.K., Barwick, S.A. and Graser, H.U. 2003. Economic evaluation of Hereford cattle breeding schemes incorporating direct and indirect measures of feed intake. *Aust. J. Agr. Res* 54: 1039-1055.

Kruger, B. and Lammerts-Imbuwa, L. 2008. Namibia National Farmers Union. Training Manual. Livestock Marketing Advisors Training Project funded by the European Commission through Oxfam Solidarity in Belgium.

Marius, L.N., Kandjou-Hambeka, M. and Jakob, A.M. 2012. Characterization of the dairy production system practiced by the livestock keepers in the selected constituencies of Namibia: A Case of Omuthiya-Guinas and Ovitoto. In: Agricola 2012. Directorate of Agricultural Research and Development, Ministry of Agriculture, Water and Forestry, Windhoek, Namibia

Marius, L.N., Shipandeni, M.N.T and Togarepi, C. 2021. Review on the status of goat production, marketing, challenges, and opportunities in Namibia. *Tropical Animal Health and Production* 53: 30. https://doi.org/10.1007/s11250-020-02468-3

Mendelsohn, J. 2006. Farming systems in Namibia. First publication by Namibia National Farmers Union, Windhoek, Namibia.

Namibia Livestock Census Report (NLCR). 2011. Ministry of Agriculture, Water, and Forestry. Directorate of Veterinary Services, Windhoek, Namibia.

Namibia Meat Board Annual Report (NMBAR). 2011. Slaughtering and Marketing Statistics of Livestock at Abattoirs in Namibia. NMBAR, Windhoek, Namibia.

National Development Plan (NDP4). 2012. Namibia's Fourth National Development Plan. National Planning Commission. Windhoek, Namibia.

Nsoso, S.J. and Morake, T.G., 1999. A critical look at the use of exotic bulls in traditional beef farming in Botswana. *South African Journal of Animal Science* 29(2):100-104.

Radhakrishna, R.B. 2001. Evaluating International Agricultural and Extension Projects: Problems, Challenges, and Strategies. *Journal of International Agricultural and Extension Education* 8 (2): 7-14.

Roessler, R., Drucker, A., Scarpa, R., Markemann, A., Lemke, U. and Thuy, L. 2008. Using choice experiments to assess smallholder farmers' preferences for pig breeding traits in different production systems in North-West Vietnam.

Ecol Econ 66(1):184-192.

Scholtz, M.M. and Theunissen, A. 2010. The use of indigenous cattle in terminal cross-breeding to improve beef cattle production in Sub-Saharan Africa. Anim. Genet. *Resource* 46: 33-39.

Scholtz, M.M., Bester, J., Mamabolo, J.M. and Ramsay, K.A. 2008. Results of the national cattle survey undertaken in South Africa, with emphasis on beef. *Appl*. *Anim*. *Husbandry Rural Dev*. 1: 1-9.

Simbaya, J. 2005. Genetic characterization of indigenous cattle breeds in Zambia which way forward? http://www-naweb.iaea.org/nafa/aph/stories/cattle-breeds-zambia.pdf

Statistical Software for Social Sciences (SPSS). 2017. IBM SPSS Statistics for Windows, version 25.0, Armonk, NY: IBM Corp.

Tada, O., Muchenje, V. and Dzama, K. 2012. Monetary value of Nguni cattle and socio-economic profiles of farmers in the low-input communal production system of Eastern Cape Province, South Africa. *Afr. J. Bus*. *Manag*. 6(45):11304–11311

Thomas, B., Togarepi, C. and Simasiku, A. 2014. Analysis of the determinants of the sustainability of cattle marketing systems in Zambezi Region of North Eastern communal area of Namibia. *International Journal of Livestock Production* 5 (7): 129-136

Togarepi, C., Thomas, B. and Kankono, M. 2016. Cattle marketing constraints and opportunities in north-central communal areas of Namibia, Ohangwena Region. *Livestock Research for Rural Development*. Volume 28, Article #132. Available online at: http://www.lrrd.org/lrrd28/7/toga28132.html

Wollny, C.B.A. 2003. The need to conserve farm animal genetic resources in Africa: should policy makers be concerned? *Ecol*. *Econ* 45(3):341-351.

African Journal of Rural Development, Vol 7(1) January-April 2022: pp.68-88. ISSN 2415-2838

Entrepreneurial orientation, learning orientation, cost focus and innovation in agri-food SME of Uganda

B. AJER,[1*] L. NGARE,[2] and I. MACHARIA[3]

[1]Department of Agricultural Economics, School of Agriculture and Enterprise Development, Kenyatta University, Kenya

[2]Department of Cooperatives and Agribusiness, The Cooperative University of Kenya

[3]Department of Agricultural Economics, School of Agriculture and Enterprise Development, Kenyatta University, Kenya

***Corresponding Author:** ajerbasil@gmail.com

ABSTRACT

Agri-food Small and Medium Enterprises (SMEs) play a key role in the economies of most developing countries. With increasing challenges and competitiveness, innovation has been shown to play a critical role in sustaining growth of the numerous agri-food SMEs in developing countries. This innovation is influenced by several factors including entrepreneurial orientation (EO) of the firm. This study introduces learning orientation and cost focus into the EO-Innovation paradigm with the aim of understanding the relationship among EO, learning orientation, cost focus and innovation. The study was conducted in the districts of Kampala, Mukono, Wakiso and Jinja in Uganda. These districts collectively have the highest concentration of agri-food firms in the country. Primary cross-sectional data were collected using semi structured questionnaires from a cross-section of 521 SMEs spread across the study area. Data were analyzed using multivariate structural equation modeling in AMOS v.23. Results suggest the importance of proactiveness in enhancing learning orientation, cost focus and innovation. On the other hand, entrepreneurial proclivity was seen to have significant influence on learning orientation and cost focus but not on innovation. The findings of this study have implications in agri-food SME learning orientation and cost focus. In essence, helping SMEs to become proactive or have high levels of proclivity would also increase their cost focus and learning orientation which are all important for the sustainability of agri-food SMEs.

Keywords: Agri-food, entrepreneurial proclivity, learning orientation, proactiveness, small and medium enterprise, Uganda

RÉSUMÉ

Les petites et moyennes entreprises (PME) agroalimentaires jouent un rôle clé dans les économies de la plupart des pays en développement. Avec les défis croissants et la compétitivité, l'innovation a été démontrée comme jouant un rôle essentiel dans la croissance durable des nombreuses PME agroalimentaires dans les pays en développement. Cette innovation est influencée par plusieurs facteurs, dont l'orientation entrepreneuriale (EO) de l'entreprise. Cette étude introduit l'orientation vers l'apprentissage et la focalisation sur les coûts dans le paradigme EO-Innovation dans le but de comprendre la relation entre l'EO, l'orientation vers l'apprentissage, la focalisation sur les coûts et l'innovation. L'étude a été réalisée dans les districts de Kampala, Mukono, Wakiso et Jinja en Ouganda. Ces districts ont collectivement la plus forte concentration d'entreprises agroalimentaires du pays. Des données primaires transversales ont été collectées à l'aide de questionnaires semi-structurés

Cite as: Ajer, B., Ngare, L. and Macharia, I. 2022. Entrepreneurial orientation, learning orientation, cost focus and innovation in agri-food SME of Uganda. *African Journal of Rural Development* 7 (1): 68-88.

Recieved: 14 January 2022
Accepted: 18 March 2022
Published: 30 April 2022

auprès d'un échantillon de 521 PME réparties dans la zone d'étude. Les données ont été analysées à l'aide de la modélisation d'équations structurelles multivariées dans AMOS v.23. Les résultats suggèrent l'importance de la proactivité dans l'amélioration de l'orientation vers l'apprentissage, la focalisation sur les coûts et l'innovation. D'autre part, la propension entrepreneuriale a été constatée pour avoir une influence significative sur l'orientation vers l'apprentissage et la focalisation sur les coûts, mais pas sur l'innovation. Les résultats de cette étude ont des implications pour l'orientation vers l'apprentissage et la focalisation sur les coûts des PME agroalimentaires. En substance, aider les PME à devenir proactives ou à avoir un niveau élevé de propension augmenterait également leur focalisation sur les coûts et leur orientation vers l'apprentissage, qui sont tous importants pour la durabilité des PME agroalimentaires.

Mots-clés : Agroalimentaire, propension entrepreneuriale, orientation vers l'apprentissage, proactivité, petites et moyennes entreprises, Ouganda

INTRODUCTION

Agriculture play an important role in the growth and development of most sub-Saharan African (SSA) countries. The sector is important for employment and poverty reduction (Christiaensen *et al.,* 2011; Christiaensen and Martin, 2018; World Bank, 2020). Its contribution to gross domestic product (GDP) and employment in these countries is enormous and cannot be ignored. In Uganda for instance, 25% of the GDP is from agriculture (UBOS, 2022), with over 70% of working population employed in the sector (World Bank, 2018; World Bank, 2021). With the renewed interest in agriculture as a facilitator of growth (Gassner *et al.,* 2019), agro- industrialization and agro-processing become key components of overall agricultural development. This agro-industrialization and agro-processing is usually dominated by agro-based small and medium enterprises (UIA, 2016) that are involved in several value adding activities in the agricultural value chain.

These agro-based small and medium enterprises (SMEs) play important role in driving demand for primary agricultural produce, in addition to providing support services and inputs to the numerous smallholder farmers (Ba *et al.,* 2019; Akumu *et al.,* 2020). Growth of these SMEs is thus critical to sustaining overall agricultural growth, in addition to sustaining the livelihoods of millions of people. In addition to increasing employment opportunities and increased market for smallholder farmers, growth of agro-based SMEs also leads to increased GDP, and expands the government tax base (Chege and Wang, 2020).

In this era of dynamic global environment, growth of agro-based SMEs requires that they become competitive (Otsuka and Ali, 2020; Otsuka and Fan, 2021). Competitive agro-based SMEs are able to adapt to the needs of the dynamic global value chains (Amanor, 2019; Kos and Kloppenburg, 2019; Feyaerts *et al.,* 2020). Consequently, with increasing global and local scale competitiveness in the agricultural sector, innovation has been shown to drive sustainability of agro-based SMEs (Caiazza *et al.,* 2014; Devaux *et al.,* 2018). In fact, studies have shown that SME innovation improved performance and profitability (Gellynck *et al.,* 2015; Ho *et al.,* 2018; Kamuri, 2021; Leo *et al.,* 2022).

With the recognition of the need to promote agro-industrialization and agro-processing as one of the growth strategies for the Ugandan economy (Government of Uganda, 2013; Government of Uganda, 2020), promoting innovation among agro-based SMEs is vital. These innovation which may involve minor to major changes in routines (Najib and Kiminami, 2011; Caiazza *et al.,* 2014; Aksoy, 2017), requires that firms learn "on the job" and undertake cost cutting strategies so as to achieve their goals. Innovation is an important characteristic of entrepreneurship that creates a difference between entrepreneurial ventures and non-entrepreneurial ones (Kanu, 2018). Consequently, an understanding of the role played by agro-based SMEs on innovation is critical to enhancing agro-based SME innovation in developing countries. This study provides empirical evidence on the influence of entrepreneurial orientation and innovation in the agro-food sector of Uganda. The finding of this study is important in developing strategies for improving SMEs growth through innovation.

LITERATURE REVIEW AND HYPOTHESES

Agri-food SME willingness to undertake entrepreneurial activities shows its level of entrepreneurial orentation (Wiklund and Shepherd, 2005). Consequently, entrepreneurial orientation refers to the extent to which each agri-food SMEs undertakes the different entrepreneurial activities (Anderson *et al.,* 2009). These entrepreneurial activities include risk taking, proactiveness and proclivity. Risk taking involves identifying and testing potential strategies that have the potential to grow the business but can also lead to losses, while proactiveness involves staying alert to address business challenges as and when they appear. On the other hand, proclivity refers to the SMEs preference for some level of risk for which if avoided and/or overcomed would lead to profits for the firm. Consequently, EO is influenced by a number of factors that are both internal and external to the SME. Previous studies have observed that each of the different EO dimensions have differential influence on performance either directly or indirectly by influencing the level of innovation undertaken by a given firm (Li *et al.,* 2009; Rauch *et al.,* 2009). While controlling firm specific characteristics, a study by Iza and Dentoni (2020) reported that a firm's EO had a negative influence on innovation aimed at improving its marketing activities. They however reported positive and significant influence of proactiveness on both customer focused innovation aimed at the product and system-focused innovation aimed at the changing the business process. Similarly, they reported an insignificant influence of intentions on all aspects of innovation. Li *et al*. (2009) reported that overall EO had a significant positive influence on firm performance, while Rezaei and Ortt (2018) reported that the association between EO and performance and innovation can be intermediated by how EO influences functional performance. The influence of EO on firm innovation and performance can thus be both direct and indirect (Diabate *et al.,* 2019; Soares and Perin, 2020).

Although there is some evidence that EO has a strong relationship with a firm's level of innovation and performance, some authors have provided counter evidence that it does not influence SME innovative performance. For instance, a study by Okangi (2019) reported a negative influence of proactiveness on profitability of construction firms in Tanzania. Moreover EO may only be relevant to innovation if applied under the right circumstances and context (Chirico *et al.,* 2011). For some firms, EO is not relevant, while for others, EO plays a vital part in enhancing innovation. In the agri-food sector for instance, changes to the product must be in line with what the consumers desire and are willing and able to pay for. Where EO leads to negative effect on innovation, the firm will not undertake such entrepreneurial activities. Similarly, the role of EO on learning orientation and cost focus are also generally lacking. This inconclusive findings on the importance EO on innovation and performance becomes realistic in some sectors of the economy and regions for which entrepreneurial orientation research is critically lacking.

Several studies on EO have either been undertaken in advanced economies (Li *et al.,* 2009; Gellynck *et al.,* 2015; Rezaei and Ortt, 2018; Gupta *et al.,* 2019; Soares and Perin, 2020) or for non-agro-food SMEs (Okangi, 2019). In the agri-food sectors of developing countries, EO perspective is unique and requires its own level of understanding with supporting evidence. This is because developing country agro-food competitive strategies requires an understanding of the developing context of EO-innovation paradigm. Whereas there are few studies that try to address this gap for developing countries, they either focus on primary production (Iza and Dentoni, 2020; Tindiwensi *et al.,* 2020) or on agro-trade (Kamuri, 2021). It is however, important to extend such analysis to agro-food value chain SMEs that are becoming important in sustaining the economy of most developing countries (Devaux *et al.,* 2018). This study introduces learning orientation and cost focus to the EO – innovation paradigm. The conceptualized relationship is presented in Figure 1. In this study, learning orientation is considered as internal feeling in the entrepreneur's mind that makes continuously evaluate and recalibrate inputs and outcome combinations for purposes of achieving growth (Gellynck *et al.,* 2015; Micheels and Gow, 2015). In other words, it is a process of continuous learning. On the other hand, cost focus in this study involves firms undertaking deliberate efforts to attract potential customers by their prices (Micheels and Gow, 2015). Both learning orientation and cost focus are expected to influence the level of innovation observed for the different SMEs. In the agro-food sector, innovation refers to changes in routine (Najib and Kiminami, 2011; Caiazza *et al.,* 2014; Aksoy, 2017; Iza and Dentoni, 2020). These changes are routine and can target the product (product innovation), the marketing process (market innovation), or the internal operations of the business (process innovation) (Ajer *et al.*, 2023).

The conceptual framework gave a rise to several hypotheses that were tested empirically. These hypotheses were:
H1a: Proactiveness has a positive effect on agri-food SME learning orientation
H1b: Proactiveness has a positive effect on agri-food SME Cost focus
H1c: Proactiveness has a positive effect on agri-food SME Innovation
H2a: Entrepreneurial proclivity has a positive effect on agri-food SME learning orientation
H2b: Entrepreneurial proclivity has a positive effect on agri-food SME Cost focus
H2c: Entrepreneurial proclivity has a positive effect on agri-food SME Innovation
H3a: Agri-food SME risk taking ability has a positive effect on agri-food SME learning orientation

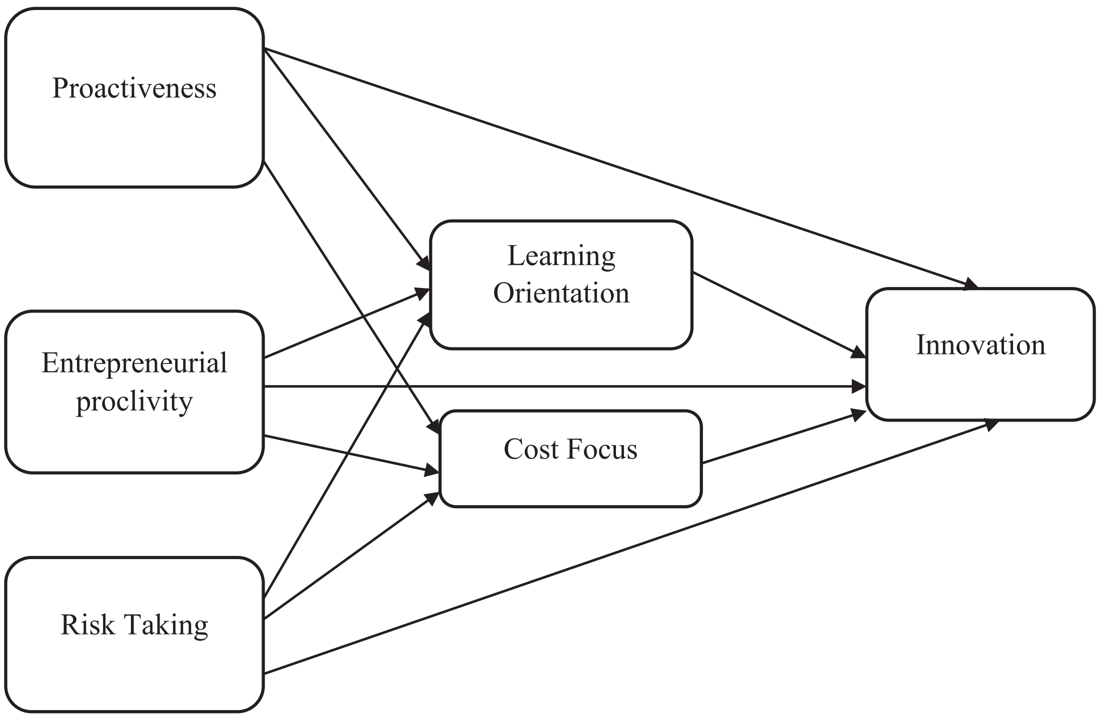


Figure 1. Conceptual framework of the study
Modified from Iza & Dentoni (2020)

H3b: Agri-food SME risk taking ability has a positive effect on agri-food SME Cost focus
H3c: Agri-food SME risk taking ability has a positive effect on agri-food SME Innovation
H4: Agri-food SME learning orientation has a positive effect on agri-food SME Innovation
H5: Agri-food SME cost focus has a positive effect on agri-food SME Innovation

METHODOLODGY

Study context and design. This study applied a cross-sectional research approach to understand the relationship among entrepreneurial orientation, learning orientation, cost focus and SME innovation. A cross-sectional design was appropriate given the nature of study which was to test the proposed hypotheses without the need for a follow-up. Consequently, primary cross-sectional data were collected from a sample of agri-food SMEs selected from Kampala, Mukono, Wakiso and Jinja districts in Uganda. The sample size for this study was determined following the Krejcie and Morgan (1970) approach. Given that there were over 100,000 SMEs in the study location (UIA, 2016), the Krejcie and Morgan approach dictated that this study takes a sample of 384 SMEs. According to Groves and Peytcheva (2008) the average non-response rate for survey research is 36%. Consequently, the sample size was corrected upwards, by 36% to 521 SMEs. This gave a total sample size of 521 SMEs. The distribution of the sample across all the study locations was proportional to the distribution of SMEs across the study locations (Table 1).With the exception of Jinja district that is geographically classified to be in Eastern Uganda, all the other three districts are classified as being located in central Uganda. In fact, Mukono and Wakiso districts both border Kampala, Uganda's capital city, while, Jinja is located some 83 kilometers east of Kampala. These four districts were purposively selected since they collectively have the highest concentration of agri-food SMEs in the country. For each of the district, a list of registered SMEs was obtained from Uganda Investments Authority. This list formed the sampling frame. Basing on the need to have realistic representation for each category of SMEs by role in the value chain (retailer, wholesaler, processor, transporter, and exporter), a representative sample was selected from each sampling frame using simple random sampling and included in the study.

Data collection and measurement of constructs. Primary data used in this study were collected using quantitative researcher administered questionnaires. The questionnaire was administered to the study participants. Specifically, the participants included agri-food SME owners or manager or their representatives in the event that they were un available but willing to delegate to another to answer the questions on their behalf. This choice was informed by the fact that as entrepreneurial ventures, it is the owners and managers who are most likely to possess the entrepreneurial traits for which the study was interested in. It is the role of owner and/or manager to direct the agri-food SME towards entrepreneurial success. Thus, interviewing the owner and/or manager would give more valid results on the aspects under study. Only those firms that gave voluntary consent to participation were included in the study. The questionnaire which contained questions on the firm's characteristics, and on the constructs under study were administered to respondents digitally using the mobile application Kobo collect. Digital data collection is preferred to hard-copy paper data collection since it saves time and tends to be more accurate if administered properly. Consequently, data were collected by a team of ten enumerators who all had experience in collecting data digitally and were first trained on the questionnaire before field work. All the enumerators also had some background in agribusiness.

The main constructs in this study were proactiveness, entrepreneurial proclivity, risk taking ability, learning orientation, cost focus and innovation. Unlike firm characteristics such as SME size that can simply be measured directly, measurement of these constructs usually requires the use of several psychometric statements which are usually answered on a Likert scale. The study adopted and modified previous used studies in measuring these constructs (Ar and Baki, 2011; Gellynck *et al.,* 2015; Aksoy, 2017; Iza and Dentoni, 2020). The modification of the constructs involved rephrasing the questions to match the context of the study area, making them more relevant to the location. In order to avoid the challenges that usually involves use of an odd numbered Likert scale, this study opted for a 6-point Likert scale. This 6-point Likert scale helps to avoid the tendency of respondent choosing a neutral option if they seem not to have a clear direction of the response (Chomeya, 2010).

Data analysis. On each day of field work, the research team performed preliminary data cleaning as a way of early detection of errors and anomalies during entry, before uploading the data on the same day on to the server. Once the field work was completed, collected data were exported to SPSS statistical package for onward analysis. Further cleaning was conducted prior to actual analysis. Data analysis involved descriptive statistics and Partial Least squares Structural equation modelling (PLS-SEM). The PLS-SEM, a multivariate analysis approached was estimated using AMOS v.23 software.

RESULTS

Sample characteristics. Majority of the Agri-food SMEs were from Kampala (37%) and Wakiso (36%). In this study, 68% of the agri-food firms interviewed could be classified as small (Table 1). Medium enterprises constituted the least category with only 14% of the SMEs. Majority (58%) of the agri-food SMEs were male owned. Slightly more than a third (35%) of the SME owners had undergraduate university degrees, while, about 27% had secondary level education, and 13% had diplomas. Under 3% of the SMEs owners had no formal education, while, over 4% had post graduate qualifications. Over 28% of agri-food SME managers had undergraduate bachelor degrees, while, about 26% had secondary school level qualifications and about 13% had various diplomas. About 12% of the SME managers had primary level education or no educational background. About 40% of the SMEs operated wholesalers, while about 25% operated as processors. Other types of agri-food SMEs included retailers (18%),

Table 1. Firmographics statistics of agri-food SME

Variable	Category	Freq.	Percent
District	Jinja	71	13.6
	Kampala	195	37.4
	Mukono	69	13.2
	Wakiso	186	35.7
Size of SME	Micro	94	18.0
	Small	354	68.0
	Medium	73	14.0
Gender of SME	Male	305	58.5
owner	Female	216	41.5
Level of Education of SME owner	No formal education	15	2.9
	Primary	48	9.2
	Ordinary Level	72	13.8
	Advanced Level	68	13.1
	Certificate	42	8.1
	Diploma	67	12.9
	Undergraduate degree	184	35.3

	Post graduate diploma	11	2.1
	Masters	11	2.1
	PhD	3	0.6
Level of Education of SME manager	No formal education	90	17.3
	Primary	24	4.6
	Ordinary Level	60	11.5
	Advanced Level	80	15.4
	Certificate	34	6.5
	Diploma	70	13.4
	Undergraduate degree	148	28.4
	Post graduate diploma	10	1.9
	Masters	5	1.0
Type of Agri-food SME Agri-food retail		92	17.7
	Agri-food Wholesale	208	39.9
	Agri-food processor	132	25.3
	Agri-food transporter	50	9.6
	Agri-food exporter	39	7.5

Reliability and Validity. Prior to assessing the relationship between entrepreneurial orientation, cost focus, learning orientation and innovation, the study first evaluated the reliability and validity of the constructs. The first focus of assessing for reliability and validity was to ensure to that all the factors loadings were above 0.5 (Hair *et al.,* 2010). Items with factors loadings below 0.5 were dropped from the analysis. Thus, for proactiveness, one item was dropped while for risk taking, two items were dropped. All the items for entrepreneurial proclivity, learning orientation, and innovation met the threshold, and thus none was dropped. Items with non-significant factor loadings were also dropped from the analysis (Table 2). Thus, in the case of cost focus, one item was dropped. Where an item was dropped, a new Cronbach alpha was computed to assess improvement in internal reliability. The final analysis showed that all the Cronbach's alphas were above 0.75, indicating good internal reliability of the constructs (Nunnally, 1994). Where an item was deleted from analysis, re-analysis of the Cronbach's alpha showed improvements in the Cronbach's alpha value. After all the items and constructs had met the threshold for factor loadings and Cronbach's alpha, analysis proceeded to assess the composite validity and convergent validity using composite reliability (CR) and Average Variance Extracted (AVE). Results presented in Table 3 showed that all the constructs had composite reliability values above 0.7, and AVE values above 0.5. A CR value of at least 0.7 confirms composite reliability while, an AVE value of 0.7 confirms convergent validity (Fornell and Larcker, 1981; Hair *et al.,* 2010).

After the reliability and validity assessment, the study then estimated the structural model to test for the hypothesized relationships. This was achieved using the multivariate analysis through structural equation modelling (SEM). During the multivariate analysis in SEM, model fit was improved by co-varying errors with high covariances. The final structural model fits indices showed good model fit (Table 2). Specifically, the ratio of the chi-square to degrees of freedom was 2.926, less than the cut-off of three. The Tucker-Lewis Index (TLI) = 0.933 (spec. 0.90) and the Comparative Fit Index (CFI) = 0.941 (spec. 0.90) all met the acceptable baseline values. Similarly, the root mean square error of approximation (RMSEA) of 0.061 was less than the acceptable maximum of 0.08. Lastly, the Standardized Root Mean Squared Residual (SRMR) value of 0.0383 was less than the acceptable maximum of 0.05 (Pavlov *et al.*, 2021). During the analysis, path analysis was performed for the pooled sample and for the sub-group sample. The grouping factors were business size, education level of the owner and manager, type of agri-food SME, and gender of the SME owner.

Table 2. Mean of scale items, internal consistency and factor loadings per construct

Construct/Scale Item	Mean	SD	CFA factor loading
Proactiveness (α1 = 0.813, α2 = 0.846)			
In dealing with other people or firms, we routinely initiate actions first and wait for the other people or firms to respond	3.83	1.15	0.618
In this firm, we have a preference for “stepping-up” to get things going as opposed to sitting and waiting for someone else to do it	4.32	1.41	0.834
In this firm, we have a tendency of planning ahead on projects	4.76	1.10	0.796
In our business operations, we anticipate future challenges, needs and changes	4.60	1.30	0.814
In dealing with other people or firms, we typically respond to actions first initiated by those other people†	3.97	1.06	0.338
Entrepreneurial proclivity (α = 0.942)			
In our firm, we encourage everyone to come up with innovative marketing approaches, knowing well that some will fail	4.62	1.26	0.783
We have a conviction that a change in the market generates a positive opportunity for our business	4.38	1.21	0.673
In our firm, we tend to dialogue more regarding opportunities rather than challenges	4.58	1.14	0.835
In our firm, we prefer to ‘play it safe’	5.09	0.88	0.745
In our firm, we prefer implementing our plans only if we are certain they will work	4.74	1.12	0.734
When it comes to solving problems in our business, we have strong preference for new and creative remedies more than the remedies of conventional wisdom	4.60	1.21	0.871
Owing to the nature of our business environment, we think it is best to explore our options cautiously	4.60	1.13	0.834
In our firm, we have preference for low-risk investment projects which have normal and certain rates of return	4.37	1.27	0.677
In our business, we generally avoid conflicts with competitors, preferring a ‘live-and-let-live’ attitude	4.75	1.27	0.836

In our business, we have strong preference for using tested and tried products or services for our business operations	4.69	1.26	0.884
Risk taking (α1 = 0.658, α2 = 0.794)			
In times of uncertainty, we adopt a brave, aggressive stance so as to maximize the chances of exploiting potential opportunities	4.15	1.47	0.518
In this firm, we have a willingness to invest a great deal of time on something that might yield high returns	4.44	1.22	0.895
In our firm, we are willing to invest a lot of money on something that might yield high returns	4.36	1.32	0.910
In general, in our firm, we do not like to take on high-risk projects†	3.95	1.35	0.217
In our firm, we usually take bold actions by trying the unknown†	3.70	1.22	0.130
Learning orientation (α = 0.946)			
Our potential to learn hastily than our competitors are the vital to our competitive advantage	4.58	1.07	0.836
Learning as a key to continuous improvement is one the basic values of our firm	4.78	1.05	0.812
In our firm, we take learning as an investment, not an expense	4.95	0.97	0.742
In our firm, learning is considered as a key ingredient required to guarantee survival in this line of business	4.71	1.19	0.830
Everyone in our firm are all in full agreement with the organizational vision	4.86	1.03	0.834
Everyone working in our firm are committed to the contribute to achieving goals of this firm	4.84	1.09	0.858
Employees of this firm look at themselves as partners in mapping the directions of the firm	4.98	1.03	0.848
All employees in our firm are fully aware that their perception of the marketplace must be examined and adapted continuously	4.63	1.29	0.865
Cost focus (α1 = 0.727, α2 = 0.889)			
In our firm, achieving a high operating efficiency is a top priority	4.91	1.07	0.852
In our firm, we have a supreme responsibility for reducing cost on our firm	4.83	1.09	0.826
In our firm, we take achievement of economies of scale or scope as an important element of our firm's strategy	4.75	1.14	0.835
We closely pay attention to the effectiveness of key processes and business operations	4.99	1.07	0.753

We do not look to improve our firm operations in order to lower our costs	3.98	1.53	0.031ns
Innovation (α = 0.811)			
We develop new ideas of improving our products/services	5.24	0.76	0.696
We implement new techniques in production and processing of our products/services	5.23	0.77	0.741
We adopt new techniques in our operations	5.19	0.71	0.768
We create new processes in our operations in order to improve efficiency	5.25	0.71	0.675

n=521
Items were measured on a 6-point Linkert scale.
Goodness of fit: Chi-square (469) = 1372.307, $p < 0.001$; chi-square/d.f. = 2.926, CFI = 0.941, TLI = 0.933, RMSEA = 0.061 (Pclose = 0.000), SRMR = 0.0383
†Indicates item that was dropped due to low loading value.
α Cronbach's alpha, α1 and α2 Cronbach's alpha before and after items were dropped

Table 3. Construct Validity of the measurement Model

Construct	1	2	3	4	5	6	CR	AVE
Proactiveness (1)	1.000						0.786	0.594
Entrepreneurial proclivity (2)	0.804	1.000					0.943	0.625
Risk Taking (3)	0.703	0.711	1.000				0.830	0.632
Learning orientation (4)	0.803	0.880	0.720	1.000			0.946	0.687
Cost Focus (5)	0.836	0.876	0.770	0.886	1.000		0.889	0.668
Innovation (6)	0.685	0.634	0.595	0.609	0.607	1.000	0.812	0.520

n=521; CR: Composite reliability, AVE: Average Variance Extracted.

Pooled and Group model results using multivariate analysis. Table 4 presents results of the multivariate analysis for the relationship between entrepreneurial orientation, cost focus learning orientation and innovation. It shows that agri-food SME's proactiveness has a positive and significant effect on learning orientation ($p<0.01$), cost focus ($p<0.01$), and innovation ($p<0.1$), thus, supporting hypothesis H1. On the other hand, entrepreneurial proclivity had a positive and significant effect on agri-food SME's learning orientation ($p<0.01$), and agri-food SME's cost focus ($p<0.01$), but had no significant effect on agri-food SME innovation, thus partially supporting hypotheses H2. Risk taking potential of the Agri-food SME did not have any significant effect on learning orientation, cost focus and innovation, thus hypotheses H3 was not supported. Similarly, both agri-food SME learning orientation and cost focus did not have any significant effect on agri-food SME innovation, thus both H4 and H5 were not supported in the pooled model.

Sub-group level analysis by size of agri-food SMEs shows differences in the relationship between entrepreneurial orientation, learning orientation, cost focus and innovation (Table 5). Specifically, the influence of agri-food SMEs proactiveness on learning orientation was only significant and positive for agri-food SMEs classified as small, but not for micro and medium agri-food firms. Similarly, the influence of agri-food SMEs proactiveness on cost focus was only significant and positive for agri-food SMEs classified as small, but not for micro and medium agri-food firms. On the other hand, the influence of agri-food SMEs proactiveness on innovation was only significant and positive for agri-food SMEs classified as medium, but not for micro and small agri-food firms. The influence of entrepreneurial proclivity in learning orientation was positive and significant for both small and medium agri-food firms, but not for micro agri-food firms.

Table 4. Pooled Model Results

Path and perspectives			Std.β	S. E	C.R	P-value	Result
Proactiveness	→	Learning orientation	0.475	0.150	3.908	0.000***	H1a Supported
Proclivity	→	Learning orientation	0.493	0.083	5.349	0.000***	H2a Supported
Risk Taking	→	Learning orientation	0.032	0.065	0.564	0.572	H3a Not supported
Risk Taking	→	Cost focus	-0.021	0.071	-0.358	0.720	H3b Not supported
Proclivity	→	Cost focus	0.643	0.088	6.710	0.000***	H2a Supported
Proactiveness	→	Cost focus	0.377	0.155	3.086	0.002 ***	H1a Supported
Learning orientation	→	Innovation	2.591	1.547	0.913	0.361	H4 Supported
Cost focus	→	Innovation	-4.157	2.214	-0.996	0.319	H5 Not supported
Proactiveness	→	Innovation	1.454	0.556	1.760	0.078*	H1c Supported
Proclivity	→	Innovation	1.156	0.685	0.823	0.410	H2c Not supported
Risk Taking	→	Innovation	-0.214	0.202	-0.673	0.501	H3c Not supported

Chi-square = 563.11; df=469; Chi-square/df=2.926; p=0.000; CFI=0.941; TLI=0.933; IFI=0.941; RM-SEA=0.061 (PCLOSE=0.000); SRMR=0.0383. S.E, C.R, P-value indicate Standardized estimates, Standard errors, Critical ratio and probability value respectively.
*, ** and *** indicate significance at p<0.1, p<0.05 and p<0.01, respectively

Table 5. Group level analysis for business size typology

Path and perspectives			Standardized estimates		
			Micro	Small	Medium
Proactiveness	→	Learning orientation	-0.077	0.499***	0.079
Proclivity	→	Learning orientation	0.869	0.512***	0.501***
Risk Taking	→	Learning orientation	0.248	-0.007	0.383
Risk Taking	→	Cost focus	-0.131	-0.065	0.063
Proclivity	→	Cost focus	0.151	0.659***	0.968***
Proactiveness	→	Cost focus	0.943	0.406***	-0.047
Learning orientation	→	Innovation	1.453	2.465	0.807
Cost focus	→	Innovation	-4.564	-3.234	-1.028
Proactiveness	→	Innovation	3.447	0.606	1.458**
Proclivity	→	Innovation	0.886	1.054	0.026
Risk Taking	→	Innovation	-0.830	-0.021	-0.424

Notes: *, ** and *** significant at p< 0.1, p< 0.05 and p<0.01, respectively

Table 6 presents results of sub-group analysis by level of education of SME owner and manager. It shows that the influence of agri-food SME proactiveness on learning orientation was positive and significant only for SME managers and owners with diploma or lower level of education. On the other hand, the influence of agri-food SME proactiveness on agri-food SME cost focus was positive and significant only for SMEs whose owners had at least an undergraduate degree, and for SME SMEs, whose owners had at most a diploma. The influence of agri-food SME entrepreneurial proclivity on learning orientation was significant for all levels of education of both owner and manager, while the influence of agri-food SME entrepreneurial proclivity on cost focus was significant for all levels of education of SMEs owners, but, only significant for SME' whose managers had at most a diploma.

Sub-group level analysis by type of agri-food SMEs indicates that agri-food SME type moderates the relationship between entrepreneurial orientation, learning orientation, cost focus and innovation. Results in Table 7 show that agri-food SMEs proactiveness had significant positive effects on learning orientation and cost focus only for agri-food transporters or exporters. There was no significant effect of proactiveness on learning orientation and cost focus for agri-food retailers, wholesalers and processors. Agri-food SME proactiveness also had a significant positive effect on agri-food processors, but not for agri-food retailers, wholesalers and transporters or exporters. Results also showed that the entrepreneurial proclivity had a significant positive effect on learning orientation for agri-food retailers, wholesalers and processors. It also had a positive and significant effect on cost focus for agri-food retailers, and processors only. Risk taking had a significant positive effect on learning orientation of agri-food processor. Agri-food SME learning orientation also had a significant effect on innovation of agri-food transporters or exporters.

Table 6. Group level analysis education level of owner and manager

Path and perspectives			Standardized estimates			
			Education Owner		Education manager	
			Degree or more	Diploma or less	Degree or more	Diploma or less
Proactiveness	→	Learning orientation	0.228	0.602***	0.314	0.522***
Proclivity	→	Learning orientation	0.709***	0.336**	0.732**	0.418***
Risk Taking	→	Learning orientation	0.040	0.075	-0.087	0.070
Risk Taking	→	Cost focus	-0.190	0.019	-0.343	0.020
Proclivity	→	Cost focus	0.695***	0.747***	0.406	0.655***
Proactiveness	→	Cost focus	0.478*	0.237	0.894	0.329***
Learning orientation	→	Innovation	-0.396	-1.272	-0.781	1.411
Cost focus	→	Innovation	0.816	-3.612	0.763	-2.587
Proactiveness	→	Innovation	0.356	3.073	1.531	1.100
Proclivity	→	Innovation	-0.181	2.532	-0.520	0.953
Risk Taking	→	Innovation	0.304	0.109	-0.171	-0.053

Notes: *, ** and *** significant at p< 0.1, p< 0.05 and p<0.01, respectively

Table 7. Group level analysis for type of agri-food SME

Path and perspectives			Standardized estimates			
			Retailer	Wholesaler	Processor	Transporter or exporter
Proactiveness	→	Learning orientation	0.101	0.494	0.076	1.535***
Proclivity	→	Learning orientation	0.800***	0.481*	0.616***	-0.262
Risk Taking	→	Learning orientation	0.112	0.019	0.304*	-0.259
Risk Taking	→	Cost focus	0.104	-0.046	0.142	-0.216
Proclivity	→	Cost focus	1.094***	0.305	0.723***	0.263
Proactiveness	→	Cost focus	-.210	0.755*	0.122	0.929***
Learning orientation	→	Innovation	1.107	-0.535	0.885	2.107*
Cost focus	→	Innovation	0.039	0.523	-0.996	-2.993
Proactiveness	→	Innovation	0.812	0.607	0.521*	0.812
Proclivity	→	Innovation	-.736	0.080	0.563	0.402
Risk Taking	→	Innovation	-0.531	0.196	0.047	0.127

Notes: *, ** and *** significant at p< 0.1, p< 0.05 and p<0.01, respectively

Table 8. Group level analysis for gender of agri-food SME owner

Path and perspectives			Standardized estimates	
			Male	Female
Proactiveness	→	Learning orientation	0.340***	0.908*
Proclivity	→	Learning orientation	0.620***	0.087
Risk Taking	→	Learning orientation	0.030	0.011
Risk Taking	→	Cost focus	-0.074	0.048
Proclivity	→	Cost focus	0.702***	0.520**
Proactiveness	→	Cost focus	0.364***	0.437
Learning orientation	→	Innovation	2.082	1.144
Cost focus	→	Innovation	-3.723	-1.511
Proactiveness	→	Innovation	1.750*	0.675
Proclivity	→	Innovation	0.997	0.701
Risk Taking	→	Innovation	-0.306	-0.147

Notes: *, ** and *** significant at p< 0.1, p< 0.05 and p<0.01, respectively

Table 8 presents results of sub-group analysis by level of education of SME owner and manager. It shows that gender of the SME owner moderates the relationship between entrepreneurial orientation, learning orientation, cost focus and innovation. Whereas the influence of agri-food SME proactiveness was significant for both male and female owned agri-food SMEs, the influence of proactiveness on agri-food firm cost focus and SME innovation were only significant for male owned firms, but not for female owned firms. Similarly, the effect of proactiveness on SME innovation was only significant for male owned agri-food firms, but not for female owned firms. The effect of entrepreneurial proclivity on learning orientation was also significant only for male owned firms but not for female owned firms. However, the effect of entrepreneurial proclivity on cost focus was significant for both male and female owned firms.

DISCUSSION

This study assessed the relationship among entrepreneurial orientation, learning orientation, cost focus and innovation for a cross-section of agri-food small and medium enterprises in Uganda. Whereas entrepreneurial orientation has many dimensions, this study focused on proactiveness, entrepreneurial proclivity and risk taking which all play a vital role in fostering innovation among small and medium enterprises. Results showed that entrepreneurial proactiveness is important for improving learning orientation of agri-food firms. Proactiveness presupposes that entrepreneurs take charge of all aspects of the business and avoid being taken by surprise on key aspects of the business. Given the uncertainty involved in business, learning becomes important for entrepreneurs who are proactive. Continuous learning has been observed to be a pre-requisite for SME business performance (Wahyuni and Sara, 2020). This explains why proactiveness positively influenced learning orientation. This finding implies that proactiveness is one of the dimensions of entrepreneurial orientation that is responsible for the observed influence of entrepreneurial orientation on learning orientation (Huang and Wang, 2011; Shaher and Ali, 2020).

Similarly, entrepreneurial firms that are usually proactive would also be cautious of their cost. This is because blindly being in charge trying to achieve business goals may instead push certain cost higher, making such firms uncompetitive. According to Forés (2019), proactiveness usually becomes costly to firms. In this study, results showed that proactiveness positively influenced cost focus. This implies that, in addition to the willingness to take up new opportunities as soon as they appear, agri-food firms also pay attention to the cost implications of such opportunities. Agro-food firms also need to understand the timeliness of their proactiveness so as to fully benefit from it (Srinivasan*et al.,* 2005; Poll*et al.,* 2018).

Results of this study also suggest that firms that are proactive are also most likely innovative. Only firms willing to take up new opportunities would also be willing to make changes to several aspects of their operations including both product and market innovations. Generally, entrepreneurial orientation is expected to influence firm innovation and innovative performance (Huang and Wang, 2011; Pérez-Luño *et al.,* 2011; Jalilvand *et al.,* 2019; Song *et al.,* 2019). However, the specific influences of each of the dimensions of entrepreneurial orientation may vary by sector and firm. For instance, a study by Khalili and Fazel (2013), observed that proactiveness did not have significant influence for petrochemical firms in Iran. However, Al Mamun and Fazal (2018) reported that proactiveness significantly influenced performance and innovation of micro enterprises in Malaysia. Proactiveness seems to be more visible to relatively small firms such those in this study. This is because proactiveness is highly linked to personal initiatives (Hahn *et al.,* 2012).

Entrepreneurial proclivity which is a firm's willingness to undertake entrepreneurial activities and processes (Zhou, 2007) influences a firm's ability and capacity to learn new strategies and approaches to doing business. Consequently, in this study, results suggest that entrepreneurial proclivity is important for agri-food firm's learning orientation. Previous studies also observed similar results (Huang and Wang, 2011; Soares and Perin, 2020). Additionally, entrepreneurial proclivity may involve regular investments into processes that improve the performance of firm. Such investments have cost implications. It is thus important that agri-food firms that practice entrepreneurial proclivity equally focus on cost, failure to do so may make the entrepreneurial efforts counterproductive. This finding suggests that even when firms are adopting entrepreneurial strategies, they need to be careful that their approaches do not make them counterproductive by increasing their cost and thus reducing their profitability.

Whereas risk taking is crucial to agribusiness, this study finds no significant influence of risk taking on learning orientation, cost focus, and innovation. Similar results were reported by Akbar *et al*. (2020). This is attributed to the fact that the firms included in this study were dealing in agri-food value chain activities beyond primary production. In the agribusiness, risk is usually more pronounced in primary production, but less encountered at levels above primary production. According to Imbiri *et al*. (2021), risk in agricultural supply chain are varied with each having a different impact and requiring a different approach to its management.

Results also show that, the observed relationship among entrepreneurial orientation, learning orientation, cost focus and innovation depends on the size of SME, education level of the owner and manager, type of SME and gender of the SME owner. These findings corroborate those of earlier studies. For instance, Etriya *et al*. (2018), reported that firm age and firm size moderated the relationship between entrepreneurial orientation and innovation. Similarly, Arzubiaga *et al*. (2018) reported that gender diversity and family involvement among board members moderated the relationship between enterpreneurial and firm performance. These findings suggest that, whereas the relationship among enterprenuerial orientation, learning orientaion, cost focus and innovation exist, it is usually context specific. This context has to be taken into consideration while formulating policies aimed at improving agro-food SME innovation.

CONCLUSION AND POLICY IMPLICATIONS

This study investigated the relationship among entrepreneurial orientation, learning orientation, cost focus and innovation. Specifically, the study was interested in understanding how the three entrepreneurial dimensions of proactiveness, risk taking and proclivity affects agri-food firms learning orientation, cost focus, and overall innovation. Results showed that all dimensions of entrepreneurial orientation are important for learning orientation, cost and overall agro-food SME innovation. Results also showed that this relationship is moderated by a number of factors including SME size, gender, education level of owner and manager and the type of agri-food SME. The findings of this study have both theoretical and practical implications. Theoretically, the findings advocate for taking into consideration the diversity of agro-food enterprises while studying entrepreneurial orientation and innovation. Practically, the findings of this study advocates for increasing the level of proactiveness of agro-food SMEs so as to improve their learning and innovation. The specific approach taken however, has to be context specific, taking into consideration the diversity of firms in the agro-food value chain.

Despite the positive findings of study, this study suffers from one main limitations. The study did not look at the specificity of the commodities in the agri-food chain. This limitation does not affect the validity of this study. Instead, it presents two interesting scenarios. First, it implies that the findings of this study may not be applied to situations that are commodity specific. In essences, the extent of applicability of the findings of this study are only limited to non-commodity specific situations. Secondly, this limitation presents an opportunity for further studies. We recommend those interested in commodity specific analysis of the EO-Innovation paradigms to consider undertaking further studies along those commodity chains.

ACKNOWLEDGEMENT

This study was supported by a competitive grant for capacity building, Training the Next Generation of Scientists for Africa, provided by the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) with funding from the Carnegie Corporation of New York.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Akbar, F., Khan, R. A., Wadood, F. and Bon, A. T. 2020. Entrepreneurial orientation dimension affects firm performance: A perspective from the Malaysian furniture industry. *Entrepreneurial Business and Economics Review* 8 (4): 157-181.

Aksoy, H. 2017. How do innovation culture, marketing innovation and product innovation affect the market performance of small and medium-sized enterprises (SMEs). *Technology in Society* 51 (4): 133-141. doi:https://doi.org/10.1016/j.techsoc.2017.08.005

Akumu, J., Odongo, W. and Mugonola, B. 2020. Determinants of contract farming for smallholder sunflower producers in northern Uganda. *African Crop Science Journal* 28 (4): 585-594.

Al Mamun, A. and Fazal, S. A. 2018. Effect of entrepreneurial orientation on competency and micro-enterprise performance. A*sia Pacific Journal of Innovation and Entrepreneurship* 12 (3): 379-398.

Ali, J., Reed, M. R. and Saghaian, S. H. 2021. Determinants of product innovation in food and agribusiness small and medium enterprises: evidence from enterprise survey data of India. *International Food and Agribusiness Management Review* 24 (5): 777-796. doi:10.22434/IFAMR2019.0210

Amanor, K. S. 2019. Global value chains and agribusiness in Africa: Upgrading or capturing smallholder production? *Agrarian South: Journal of Political Economy* 8 (1-2): 30-63.

Ar, I. M. and Baki, B. 2011. Antecedents and performance impacts of product versus process innovation: Empirical evidence from SMEs located in Turkish science and technology parks. *European Journal of Innovation Management* 14(2):172-206.doi:https://doi.org/10.1108/14601061111124885

Arzubiaga, U., Iturralde, T., Maseda, A. and Kotlar, J. 2018. Entrepreneurial orientation and firm performance in family SMEs:

the moderating effects of family, women, and strategic involvement in the board of directors. *International Entrepreneurship and Management Journal* 14 (1): 217-244.

Ba, H. A., de Mey, Y., Thoron, S. and Demont, M. 2019. Inclusiveness of contract farming along the vertical coordination continuum: Evidence from the Vietnamese rice sector. *Land Use Policy* 87: 104050. doi:https://doi.org/10.1016/j.landusepol.2019.104050

Bamfo, B. A. and Kraa, J. J. 2019. Market orientation and performance of small and medium enterprises in Ghana: The mediating role of innovation. *Cogent Business and Management* 6 (1): 1605703.

Caiazza, R., Volpe, T. and Audretsch, D. 2014. Innovation in agro-food chain: Policies, actors and activities. *Journal of Enterprising Communities: People and Places in the Global Economy* 8 (3): 180-187. doi:https://doi.org/10.1108/JEC-06-2014-0009

Chege, S. M. and Wang, D. 2020. Information technology innovation and its impact on job creation by SMEs in developing countries: an analysis of the literature review. *Technology Analysis and Strategic Management* 32 (3): 256-271. doi:https://doi.org/10.1080/09537325.2019.1651263

Chirico, F., Sirmon, D. G., Sciascia, S. and Mazzola, P. 2011. Resource orchestration in family firms: Investigating how entrepreneurial orientation, generational involvement, and participative strategy affect performance. *Strategic Entrepreneurship Journal* 5 (4): 307-326.

Chomeya, R. 2010. Quality of psychology test between Likert scale 5 and 6 points. *Journal of Social Sciences* 6 (3): 399-403.

Christiaensen, L. and Martin, W. 2018. Agriculture, structural transformation and poverty reduction: Eight new insights. *World Development* 109: 413-416.

Christiaensen, L., Demery, L. and Kuhl, J. 2011. The evolving role of agriculture in poverty reduction—An empirical perspective. *Journal of Development Economics* 96 (2): 239-254.

Devaux, A., Torero, M., Donovan, J. and Horton, D. 2018. Agricultural innovation and inclusive value-chain development: a review. *Journal of Agribusiness in Developing and Emerging Economies* 8 (1): 99-123. doi:https://doi.org/10.1108/JADEE-06-2017-0065

Diabate, A., Sibiri, H., Wang, L. and Yu, L. 2019. Assessing SMEs' sustainable growth through entrepreneurs' ability and entrepreneurial orientation: An insight into SMEs in Côte d'Ivoire. *Sustainability* 11 (24): 7149.

Dibrell, C., Craig, J. B. and Hansen, E. N. 2011. How managerial attitudes toward the natural environment affect market orientation and innovation. *Journal of Business Research* 64 (4): 401-407.

Eton, M., Mwosi, F., Okello-Obura, C., Turyehebwa, A. and Uwonda, G. 2021. Financial inclusion and the growth of small medium enterprises in Uganda: empirical evidence from selected districts in Lango sub-region. *Journal of Innovation and Entrepreneurship* 10: 23. doi:https://doi.org/10.1186/s13731-021-00168-2

Etriya, E., Scholten, V., Wubben, E., Kemp, R. and Omta, O. 2018. The importance of innovation adoption and generation in linking entrepreneurial orientation with product innovation and farm revenues. *International Food and Agribusiness Management Review* 21 (7): 969-988.

Feyaerts, H., Van den Broeck, G. and Maertens, M. 2020. Global and local food value chains in Africa: A review. *Agricultural Economics* 51 (1): 143-157.

Forés, B. 2019. Beyond gathering the 'lowhanging fruit'of green technology for improved environmental performance: an empirical examination of the moderating effects of proactive environmental management and business strategies. *Sustainability* 11 (22): 6299.

Fornell, C. and Larcker, D. F. 1981. Structural Equation Models with Unobservable Variables and Measurement Error: Algebra and Statistics. *Journal of Marketing Research* 382-388. doi:https://doi.org/10.2307/3150980

Gassner, A., Harris, D., Mausch, K., Terheggen, A., Lopes, C., Finlayson, R. F. and Dobie, P. 2019. Poverty eradication and food security through agriculture in Africa: Rethinking objectives and entry points. *Outlook on Agriculture* 48 (4): 309-315.

Gellynck, X., Cárdenas, J., Pieniak, Z. and Verbeke, W. 2015. Association between innovative entrepreneurial orientation, absorptive capacity, and farm business performance. *Agribusiness* 31 (1): 91-106.

Government of Uganda. 2013. Uganda Vision 2040. Kampala, Uganda: National Planning Authority. Retrieved from http://www.npa.go.ug/uganda-vision-2040/

Government of Uganda. 2020. The Third National Development Plan (NDP III). Kampala, Uganda: National Planning Authoriy - Uganda. Retrieved from http://www.npa.go.ug/wp-content/uploads/2020/08/NDPIII-Finale_Compressed.pdf

Gupta, V. K., Niranjan, S. and Markin, E. 2019. Entrepreneurial orientation and firm performance: the mediating role of generative and acquisitive learning through customer relationships. *Review of Managerial Science* https://doi.org/10.1007/s11846-019-00327-6.

Hahn, V. C., Frese, M., Binnewies, C. and Schmitt, A. 2012. Happy and proactive? The role of hedonic and eudaimonic well–being in business owners' personal initiative. *Entrepreneurship Theory and Practice* 36 (1): 97 - 114.

Hair, J. F., Anderson, R. E., Tatham, R. L. and Black, W. C. 2010. Multivariate Data Analysis with Readings. Upper Saddle River, NJ.: Prentice-Hall.

Hansen, E., Dibrell, C. and Down, J. 2006. Market orientation, strategy, and performance in the primary forest industry. *Forest Science* 52 (3): 209-220.

Ho, K. L., Nguyen, C. N., Adhikari, R., Miles, M. P. and Bonney, L. 2018. Exploring market orientation, innovation, and financial performance in agricultural value chains in emerging economies. *Journal of Innovation and Knowledge* 3 (3): 154-163. doi:https://doi.org/10.1016/j.jik.2017.03.008

Huang, S. K. and Wang, Y. L. 2011. Entrepreneurial orientation, learning orientation, and innovation in small and medium enterprises. *Procedia-Social and Behavioral Sciences* 24: 563-570.

Imbiri, S., Rameezdeen, R., Chileshe, N. and Statsenko, L. 2021. A novel taxonomy for risks in agribusiness supply chains: a systematic literature review. *Sustainability* 13 (16): 9217. doi: https://doi.org/10.3390/su13169217

Iza, C. L. and Dentoni, D. 2020. How entrepreneurial orientation drives farmers' innovation differential in Ugandan coffee multi-stakeholder platforms. *Journal of Agribusiness in Developing and Emerging Economies* 10 (5): 629-650. doi:https://doi.org/10.1108/JADEE-01-2020-0007

Jalilvand, M. R., Nasrolahi Vosta, L., Khalilakbar, R., Khazaei Pool, J. and Tabaeeian, R. A. 2019. The effects of internal marketing and entrepreneurial orientation on innovation in family businesses. *Journal of the Knowledge Economy* 10 (3): 1064-

1079.

Kamuri, S. 2021. Creating as an entrepreneurial competence, innovation and performance of value-system actors in Kenya's leather industry. *Scientific African* 11: e00664. doi:https://doi.org/10.1016/j.sciaf.2020.e00664

Kanu, A. 2018. Benefits and barriers of entrepreneurial ventures:-A literature review point of view. *International Journal of Entrepreneurship and Business Innovation* 1 (1): 27-48.

Khalili, H. and Fazel, A. 2013. The influence of entrepreneurial orientation on innovative performance: Study of a petrochemical company in Iran. *Journal of Knowledge-based Innovation in China* 5 (3): 262-278.

Kintu, I. and Venter, R. 2019. Core values as drivers of entrepreneurial performance: A study of SMEs in Uganda's central region. *Development Southern Africa* 36 (5) 651-665. doi: https://doi.org/10.1080/0376835X.2018.1559041

Kos, D. and Kloppenburg, S. 2019. Digital technologies, hyper-transparency and smallholder farmer inclusion in global value chains. *Current Opinion in Environmental Sustainability* 41: 56-63.

Leo, R. M., Camboim, G. F., Avila, A. M., Reichert, F. M. and Zawislak, P. A. 2022. Innovation capabilities in agribusiness: evidence from Brazil. *RAUSP Management Journal* 57: 65-83. doi:https://doi.org/10.1108/RAUSP-02-2021-0019

Li, Y. H., Huang, J. W. and Tsai, M. T. 2009. Entrepreneurial orientation and firm performance: The role of knowledge creation process. *Industrial Marketing Management* 38 (4): 440-449.

Micheels, E. T. and Gow, H. R. 2008. Market orientation, innovation and entrepreneurship: An empirical examination of the Illinois beef industry. *International Food and Agribusiness Management Review* 11: 31-56.

Micheels, E. T. and Gow, H. R. 2015. The effect of market orientation on learning, innovativeness, and performance in primary agriculture. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 63 (2): 209-233.

Muriithi, S. M. 2017. African Small and Medium Enterprises (SMEs) Contributions, Challenges and Solutions. *European Journal of Research and Reflection in Management Sciences* 5 (1): 36-48.

Najib, M. and Kiminami, A. 2011. Innovation, cooperation and business performance: Some evidence from Indonesian small food processing cluster. *Journal of Agribusiness in Developing and Emerging Economies* 1 (1): 75-96. doi:https://doi.org/10.1108/20440831111131523

Narver, J. C. and Slater, S. F. 1990. The effect of a market orientation on business profitability. *Journal of Marketing* 54 (4): 20 - 35.

Nunnally, J. C. 1994. Psychometric theory. 3rd ed. New York: McGraw-hill education.

Okangi, F. P. 2019. The impacts of entrepreneurial orientation on the profitability growth of construction firms in Tanzania. *Journal of Global Entrepreneurship Research* 9: 14. doi:https://doi.org/10.1186/s40497-018-0143-1

Otsuka, K. and Ali, M. 2020. Strategy for the development of agro-based clusters. *World Development Perspectives* 20: 100257.

Otsuka, K. and Fan, S. (Eds.). 2021. Agricultural Development: New Perspectives in a Changing World. Washington, DC: International Food Policy Research Institute. doi:https://doi.org/10.2499/9780896293830

Pavlov, G., Maydeu-Olivares, A. and Shi, D. 2021. Using the standardized root mean squared residual (SRMR) to assess exact fit in structural equation models. *Educational and Psychological Measurement* 81 (1): 110-130. doi:https://doi.org/10.1177%2F0013164420926231

Pérez-Luño, A., Wiklund, J. and Cabrera, R. V. 2011. The dual nature of innovative activity: How entrepreneurial orientation influences innovation generation and adoption. *Journal of business Venturing* 26 (5): 555-571.

Peter, T. and Cathy, I. M. 2015. Networking for SMES in Uganda: A conceptual paper. *African Journal of Business Management* 9 (2): 43-49.

Poll, R., Polyvyanyy, A., Rosemann, M., Röglinger, M. and Rupprecht, L. 2018. Process forecasting: Towards proactive business process management. pp. 496-512. In: Weske, M., Weber, I., Montali, M. and vom Brocke, J. (Eds.), International Conference on Business Process Management. Cham: Springer.

Rauch, A., Wiklund, J., Lumpkin, G. T. and Frese, M. 2009. Entrepreneurial orientation and business performance: An assessment of past research and suggestions for the future. *Entrepreneurship Theory and Practice* 33 (3): 761-787.

Rezaei, J. and Ortt, R. 2018. Entrepreneurial orientation and firm performance: the mediating role of functional performances. *Management Research Review* 41 (7): 878-900.

Shaher, A. T. and Ali, K. 2020. The effect of entrepreneurial orientation on innovation performance: The mediation role of learning orientation on Kuwait SME. *Management Science Letters* 10 (16): 3811 - 3820.

Soares, M. D. and Perin, M. G. 2020. Entrepreneurial orientation and firm performance: an updated meta-analysis. *RAUSP Management Journal* 55 (2): 143-159.

Song, W., Ma, X. and Yu, H. 2019. Entrepreneurial orientation, interaction orientation, and innovation performance: A model of moderated mediation. *Sage Open* 9 (4): https://doi.org/10.1177/2158244019885143.

Srinivasan, R., Rangaswamy, A. and Lilien, G. L. 2005. Turning adversity into advantage: does proactive marketing during a recession pay off? *International Journal of Research in Marketing* 22 (2): 109 - 125.

Tindiwensi, C. K., Munene, J. C., Sserwanga, A., Abaho, E. and Namatovu-Dawa, R. 2020. Farm management skills, entrepreneurial bricolage and market orientation. *Journal of Agribusiness in Developing and Emerging Economies* 10 (5): 717-730. doi:doi:https://doi.org/10.1108/JADEE-08-2019-0111

UBOS. 2022. Uganda Bureau of Statistics. Retrieved from Uganda Bureau of Statistics Website: https://www.ubos.org/explore-statistics/2/

UIA. 2016. SMEs Driving the Economy. Retrieved April 30, 2022, from Uganda Investment Authority: https://www.ugandainvest.go.ug/smes-driving-economy/

Wahyuni, N. M. and Sara, I. M. 2020. The effect of entrepreneurial orientation variables on business performance in the SME industry context. *Journal of Workplace Learning* 32 (1): 35-62.

Wiklund, J. and Shepherd, D. 2005. Entrepreneurial orientation and small business performance: a configurational approach. Journal of business venturing. 20 (1): 71-91.

World Bank. 2007. World Development Report 2008: Agriculture for Development. Washington, DC: The World Bank.

World Bank. 2018. Closing the Potential-Performance Divide in Ugandan Agriculture. Washington, DC: The World Bank.

World Bank. 2020. Poverty and Shared Prosperity 2020: Reversals of Fortune. Washington, DC: The World Bank. doi:10.1596/978-1-4648-1602-4

World Bank. 2021. Employment in agriculture

(% of total employment) (modeled ILO estimate) - Uganda. Retrieved September 12, 2022, from World Bank: https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=UG

Zhou, L. 2007. The effects of entrepreneurial proclivity and foreign market knowledge on early internationalization. *Journal of World Business* 42 (3): 281-293. doi:https://doi.org/10.1016/j.jwb.2007.04.009

African Journal of Rural Development, Vol. 7 (1): January-April 2022: pp. 89-110. ISSN 2415-2838

Fuel from the Farm: An analysis of the profitability and factors driving farmers' decisions to produce bioethanol from cassava in Northern Uganda

D. OPOLOT, [1] J. ILUKOR,[2,1] S. B. MUKASA[3] and J. MUGISHA[1]

[1]Department of Agribusiness and Natural Resource Economics, Makerere University, P.O. Box 7062, Kampala, Uganda
[2] The Living Standards Measurement Study (LSMS), Survey Unit, Development Data Group, World Bank, Kampala, Uganda
[3]Department of Agricultural Production, Makerere University, P.O. Box 7062, Kampala, Uganda
Corresponding Author: dopolot8@gmail.com

ABSTRACT

This study examined profitability of producing bioethanol and factors that drive farmers' decisions to produce bioethanol from cassava. Although small scale production of bioethanol was found to be profitable, selling cassava dry chips was found to be more profitable. In addition, selling fresh cassava roots was also more profitable than small scale production of bioethanol. However, bioethanol producers who grow cassava and process bioethanol get more returns on investment compared to those who buy cassava chips and process bioethanol. Sensitivity analysis results revealed that 40% decrease or increase in price of dry chips and firewood contributed remarkable change on profitability of bioethanol. The results also reveal that growing improved cassava variety, ownership of land of 2 acres (≈1 ha), allocating more proportion of land to cassava, engagement in off-farm work and profitability of bioethanol, positively influenced farmers' decisions to produce bioethanol while sex of household head, Pentecostal Christian, profitability of dry chips and condition of the road negatively influenced farmers' decisions to produce bioethanol. The paper concludes that promoting bioethanol production from cassava will require meeting the food security demands by increasing cassava production through expansion of acreage and promoting planting of improved high yielding varieties. This should be coupled with reduction of costs of processing bioethanol and expansion of market opportunities through extra value addition

Key words: Cassava bioethanol, drivers of production, profitability analysis, sensitivity analysis, Uganda

RÉSUMÉ

Cette étude examine la rentabilité de la production de bioéthanol et les facteurs qui influencent les décisions des agriculteurs de produire du bioéthanol à partir du manioc. Bien que la production de bioéthanol à petite échelle se soit avérée rentable, la vente de copeaux de manioc secs s'est révélée plus rentable. De plus, la vente de racines de manioc fraîches était également plus rentable que la production de bioéthanol à petite échelle. Cependant, les producteurs de bioéthanol qui cultivent le manioc et le transforment en bioéthanol obtiennent un meilleur retour sur investissement que ceux qui achètent des copeaux de manioc et les transforment en bioéthanol. Les résultats de l'analyse de sensibilité ont révélé qu'une diminution ou une augmentation de 40 % du prix des copeaux secs et du bois de chauffage entraînait un changement remarquable de la rentabilité du bioéthanol.

Cite as: Opolot, D., Ilukor, J., Mukasa, S. and Mugisha, J. 2022. Fuel from the Farm: An analysis of the profitability and factors driving farmers' decisions to produce bioethanol from cassava in Northern Uganda. *African Journal of Rural Development* 7 (1): 89-110.

Received: 11 November 2021
Accepted: 31 January 2022
Published: 30 April 2022

Les résultats révèlent également que la culture d'une variété de manioc améliorée, la possession d'un terrain de plus de 2 acres (environ 1 hectare), l'allocation d'une plus grande proportion de terre au manioc, l'engagement dans un travail hors exploitation agricole et la rentabilité du bioéthanol influencent positivement les décisions des agriculteurs de produire du bioéthanol, tandis que le sexe du chef de ménage, l'appartenance à l'église pentecôtiste, la rentabilité des copeaux secs et l'état de la route influencent négativement les décisions des agriculteurs de produire du bioéthanol. Le document conclut que la promotion de la production de bioéthanol à partir du manioc nécessitera de répondre aux exigences de sécurité alimentaire en augmentant la production de manioc par l'expansion des surfaces cultivées et la promotion de la plantation de variétés améliorées à haut rendement. Cela devrait s'accompagner d'une réduction des coûts de transformation du bioéthanol et d'une expansion des opportunités de marché grâce à une valeur ajoutée supplémentaire.

Mots-clés : Manioc bioéthanol, facteurs de production, analyse de rentabilité, analyse de sensibilité, Ouganda

INTRODUCTION

As the current global population continues to grow especially in developing countries like Uganda where the population growth rate (3.3%) is higher than the growth in agricultural sector (1.5%) (World Bank, 2016), the demand for food and fuel to enable people live a healthy and an improved life style continues to grow. Food demand is expected to increase anywhere between 59% to 98% by 2050 (Valin *et al.,* 2014). Similarly, fuel demand is expected to increase by 28% by 2040 (IEA, 2017). These increases in food and energy demand means extracting more fuel from the farms. However, food security activists contend that this is expected to worsen the food insecurity situation. Jean Ziegler, the United Nations (UN) special rapporteur on the Right to Food from 2000-2008 argued that, burning hundreds of millions of tonnes of staple foods to produce biofuels is a crime against humanity (Mathews, 2012). Similar sentiments have been echoed by Monbiot (2007) who castigated Swaziland's Government for deciding to export biofuel made from cassava when 40% of its population was facing acute food shortages. The argument is that extracting fuel from the farm will drive prices for food high thus leading to reduced food availability and increased land prices which results into increased hunger, land grabbing, environmental damage and loss of life (Mitchell, 2008; Schmitz and Moleva, 2013). Monbiot (2007) argued that even when the price of food was low, 850 million people went hungry because they could not afford to buy it and if promoting biofuels is not reversed, humanitarian impact will be greater than the Iraq war. Ziegler *et al*. (2011) contends that, every five seconds, a child under the age of 10 dies directly or indirectly because of hunger somewhere in the world.

The advocates of biofuel production on the other side argue that rapid food price increases, hunger and malnutrition have been widespread even before the boom on biofuel occurred (Tenenbaum, 2008). They argue that biofuels can play a very significant role in revitalizing agricultural land use and livelihoods in rural areas. Increased prices could benefit smallholders farmers and could drive farmers to adopt improved technologies thus leading to significant increase in both yields and incomes which is key to poverty reduction (Cotula *et al.,* 2008). Mathews (2012) argued that farmers in developing countries lack income to purchase inputs on the open market, therefore governments need to promote biofuels to generate income, employment, and export earning to boost input use and agricultural productivity. Production and processing of bioethanol also helps in reducing post-harvest losses in crops like cassava. FAO (2011) report notes that 40% of post-harvest losses in cassava and other root crops are reported in sub–Saharan Africa, 35% in Latin America and 31% in South and South-East Asia. Moreover, there is no guarantee that food production will increase if bioethanol production is avoided (Ejigu, 2008). Yet, bioethanol production has a potential to increase agricultural production which in turn will lead to increased food and fuel supplies by increasing input use (Kueneman *et al.,* 2012; Kristensen *et al.,* 2014; Thatoi *et al.,* 2016).

In Uganda, the demand for bio-fuel is expected to grow from 187 million litres in 2012 to 220 million litres by 2022 (NARO and NEMA, 2010). While sorghum, maize, millet and sugarcane molasses feedstocks are used for bioethanol production in Uganda, cassava is also commonly used and preferred feedstock to produce bioethanol. This is attributed to: firstly, the high productivity, high starch content and the availability of cassava (Adiotomre, 2015). Secondly, unlike other crops, cassava can be harvested all year round and can tolerate harsh natural conditions, especially drought (Jakrawatana *et al.,* 2015). Moreover, it can be planted on marginal lands where other crops do not grow well (Zhang *et al.,* 2003). Lastly, the processing of cassava into bioethanol is more efficient compared to crops like sugarcane, maize, wheat, and sweet potato (Liu *et al.,* 2013). For instance, cassava has a conversion rate of about 180 litres per tonne of cassava roots compared to 70 and 80 litres per tonne of sugarcane and sorghum, respectively (Balat and Balat, 2009; Ohimain, 2015)

Although production of bioethanol from cassava is the preferred option for producing biofuel and presents significant opportunities for improving rural livelihoods, current cassava bioethanol production in Uganda is low. Only about 11% of the bioethanol in Uganda is produced from cassava (Mutyaba *et al.,* 2016) and over 90% of bioethanol produced by smallholder farmers is mostly for local consumption and about 10% for industrial uses (Mutyaba *et al.,* 2016). This study examined the reasons for the low level of production of bioethanol from cassava. Specifically, the study examines whether or not, the smallholder farmers are making profits from the current cassava bioethanol production. The analysis of profitability is important because it influences investment decisions (Nguyen and Nguyen, 2020). Such investment decisions include decisions to process cassava into bioethanol or not. The study also examined the profitability of processing cassava into dry chips and selling cassava in form of fresh tubers. The study involved sensitivity analysis to incorporate uncertainty into economic evaluation so as to determine the best possible scenario of maximizing benefit from bioethanol production. In addition, the study also examined the factors that influence farmers' decisions to produce bioethanol.

Cassava production in Uganda. In Uganda, Cassava is the second most important staple crop after bananas (UBOS, 2010). The crop is reportedly more profitable than maize with a profit of about 30-60 Uganda shillings per kilogram of dry chips compared to 10-20 Uganda shillings per kilogram of dried maize grain at farm gate price (USAID, 2010). Mutyaba *et al.* (2016) indicated that production and processing of cassava has a potential of saving the country an estimated 300 million United States Dollars used for importing other products such as wheat that could otherwise be substituted by processed cassava products into products such as high quality cassava flour (HQCF). However, data from the Food and Agriculture Organization of the United Nations (FAOSTAT, 2017) revealed that production volumes of cassava between 2004 and 2016 in Uganda generally declined as shown in Figure 1.

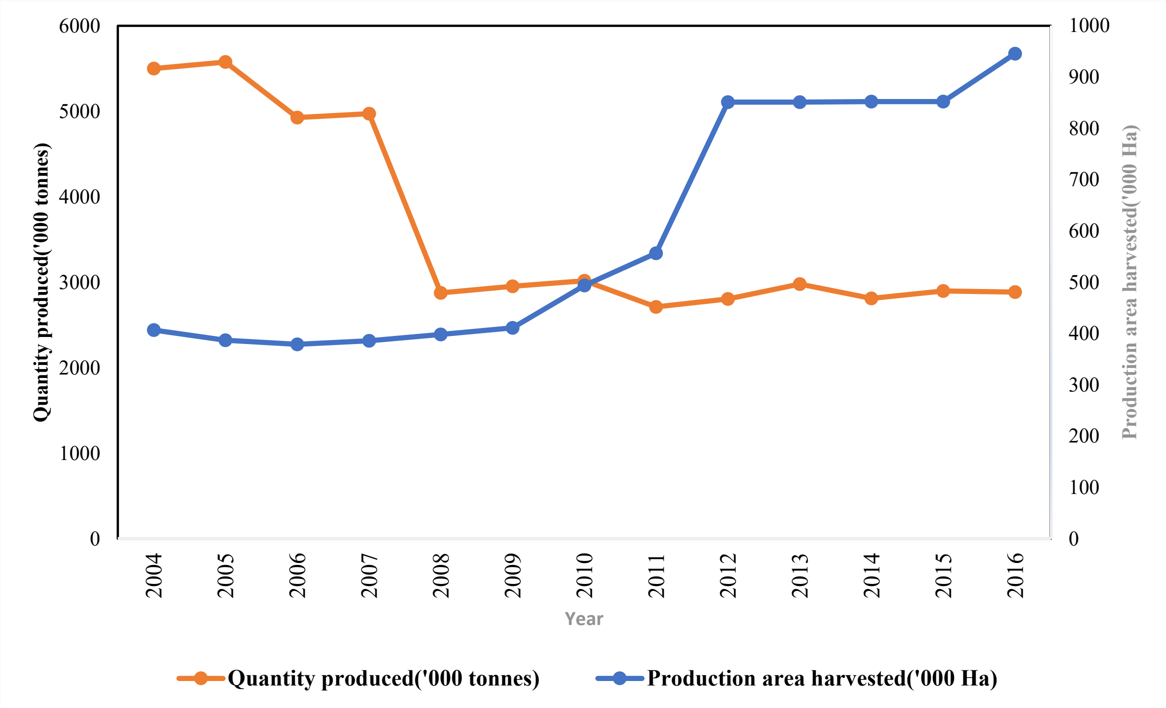


Figure 1. Area under cassava and volumes produced between 2005 and 2016 in Uganda
Source: (FAOSTAT, 2017) Retrieved 8th August 2017

The decline in volumes produced is attributed to re-occurrence and spread of Cassava Brown Streak Disease (CBSD) into new areas, a devastating cassava viral disease (Alicai *et al.,* 2007). Despite the decline, the area under cultivation increased steadily during the period probably indicating importance of cassava in farmer households. In 2009, the Government of Uganda with the financial support from the World Bank established the Cassava Regional Centre of excellence under the East African Agricultural Productivity Programme (EAAPP). One of the mandates of the centre was to generate cassava technologies that address the challenges of cassava productivity such as development of high yielding cassava varieties that are resistant to cassava pests and diseases. Additionally, the centre was expected to spearhead commercialization of cassava and its by-products. Thus, early maturing, high yielding and CBSD tolerant varieties such as NAROCass 1, NASE 19 and NASE 14, among others, were released to boost production and commercialization of cassava (Mukasa, 2015).

However, with expected increase in production, the other challenges such as perishability of cassava roots due to rapid post-harvest physiological deterioration presents serious impediment to the production and commercialization of cassava especially during periods of glut supply (Naziri *et al.,* 2014). For instance, in the season or year when there is glut supply, farmers are forced to sell their cassava at very low prices to avoid spoilage hence most farmers plant less the season that follows. This sometimes leads to insufficient supplies in next season while in certain periods of the planting season, farmers are offered prices that are more attractive which encourages them to plant more than they can store in the next season (Abass *et al.,* 2012). Other options such as storage of roots in the garden and only harvesting when needed are not sustainable. This is compounded by the fact that some of the newly released varieties do not store for more than one and half years before they rot while in the field. Moreover, selling as fresh tubers is also hindered by long distance to the markets, lack of access to market information and poor roads.

On the other hand, while interventions such as processing of cassava into dry chips is particularly important in addressing the challenge of perishability, quality is compromised by the nature of peeling and drying done on roadsides and bare floors drastically reducing the value of the chips. Adebayo *et al*. (2012) asserts that this vicious cycle causes major distortions in the farmers' production system and leads to disincentives as well as lack of confidence in cassava as a cash crop. Therefore, processing cassava into bioethanol could play an important role in addressing some of the challenges.

Cassava bioethanol production in Uganda. The annual demand for bioethanol in Uganda is estimated to be 16 million litres and it is expected to grow at an annual rate of 10-15% (Kleih *et al*., 2012). However, 90% of the bioethanol in Uganda is imported (Kleih *et al*., 2012) and only 10% is produced within Uganda. Of the 10% produced within the country, 90% is produced by smallholder farmers and it is mostly for local consumption with only 10% being for industrial use (Mutyaba *et al*., 2016). Production of bioethanol from cassava is done by the resource-poor smallholder farmers who cultivate less than 2 hectares of land (1 ha) using rudimentary tools (Mutyaba *et al*., 2016; Nakabonge *et al*., 2017). These resource-poor farmers also account for 85% of total cassava production in the country and only about 2 % of the production is processed in to bioethanol (Nuwamanya *et al*., 2012).

The main industrial users of bioethanol in Uganda include research laboratories, schools, pharmaceutical and cosmetic industries. Research laboratories use bioethanol as preservative of biological specimens, cleaning agent, a reagent for laboratory analysis and sanitary purposes in hospitals and schools (Graffham and Kalunda, 2000). Brewing companies especially Uganda Breweries use bioethanol to make alcoholic beverages such as Uganda Waragi, industries use bioethanol to make cosmetics while pharmaceutical industries use it in the preparation of essences and flavourings in pharmaceutical products (Graffham and Kalunda, 2000).

The production of bioethanol by smallholder cassava farmers is characterized by use of rudimentary tools and equipment and firewood as the source of energy and all these compromise its quality (Nuwamanya *et al*., 2012; Ohimain, 2015). A summary of the production process of bioethanol as shown in Figure 2 indicates that the cycle takes a minimum of two weeks for the distillation process to occur. Moreover, the equipment used is unable to produce anhydrous ethanol, but can distil ethanol to 50–70%. Large scale cassava ethanol extraction factory has been built in Lira district in Northern Uganda for industrial extraction of bioethanol from cassava and has led to increased cassava production northern Uganda because farmers have assured market (Oketch, 2016).

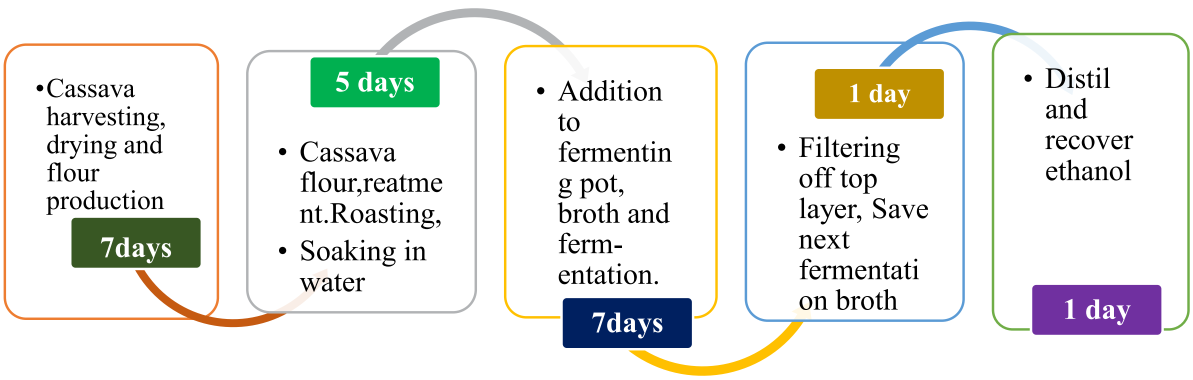


Figure 2. Production process for bioethanol production by smallholder cassava farmers in Northern Uganda
Adapted from: (Nuwamanya, 2017 Unpublished)

METHODOLOGY

Study area and data collection. The data used in this study were collected in June 2016 in Apac, Kole and Lira districts in Northern Uganda. The districts were selected because cassava is a staple in the three districts and is eaten and processed in different forms such as fresh tubers, dry chips and bioethanol. Production of bioethanol in the three districts is done by individual farmers using rudimentary processing technology from cassava chips bought from the market or from cassava grown in their own farms. Specifically, Apac and Kole district were the leading cassava producing district in the country allocating 42,836 ha and producing 239,932 Mt of Cassava (UBOS, 2010). On the other hand, Lira district is the end market for most of the cassava products such as fresh tubers and dry chips. Lira district also hosts the only bioethanol processing factory called Kamtech Technologies located in Northern Uganda (Oketch, 2016).

A multistage sampling technique was employed to get a representative sample of farmers from the study area. In the first stage, one sub county was purposively selected from each of the three districts based on numbers of active farmers involved in cassava production. Through the local and farmer group leaders, farmers who either grew cassava or did not grow cassava but were involved in processing and marketing of cassava products and belonged to each of the selected sub counties were purposively selected. A total of 515 farmers; 165 farmers from Chegere in Apac, 265 from Bala in Kole and 85 farmers from Adekokwok in Lira district were selected. In the third stage, from the list of 515 farmers selected in the second stage, proportionate sampling was used whereby the number of respondents were randomly selected based on the number of farmers purposively selected in each sub county during second stage. Specifically, 76 farmers from Chegere in Apac district, 132 farmers from Bala in Kole and 42 farmers from Adekokwok in Lira were selected for the interview. Overall, 250 respondents were selected for the study. The results are presented for 243 farmer beneficiaries from data cleaning exercise undertaken. To eliminate bias, farmers who were selected but could not be accessed at the time of interview were replaced by other farmers within the sampling frame. The quantitative data collected included; all household activities (farm and non-farm), enterprise types, crop area and production levels, input and expenditures for the first and second season. Socio-economic and institutional data such as household characteristics, land size and farm characteristics and investment in assets were also captured. Other questions in the questionnaire tool administered were related to the supply of on-farm family and hired labour and educational status and religion, costs and revenues incurred in production, processing and marketing of cassava products including fresh tubers, bioethanol and dry chips.

Empirical methods. To examine whether smallholder farmers were making profit from the cassava bioethanol production compared to selling cassava dry chips, gross margins analysis approach was employed. Although other methods such as cost benefit analysis, and enterprise budgeting can be used to assess profitability, the gross margins approached was used because it is reasonably straight forward, easy to understand and allows for easier comparison (Rushton, 2009). Additionally, the focus of the study was mainly on financial outputs without fixed costs. Rushton (2009) argues that gross margins are computed as the difference between total revenue (TR) and Total Variable Costs (TVC) which is expressed mathematically in the equation below:

$$GM_i = TR - TVC \qquad 1$$

Where GM= Gross margin

$$TR = \sum_{j=1}^{n} P_j Q_j \, ; for\ j = 1,2,3 \ldots n$$

$$TVC = \sum_{i=1}^{n} P_i X_i \, ; for\ i = 1,2,3 \ldots n$$

Where GM= Gross margin of ith cassava product category in Uganda shillings normalized at hectare level

P_j=Unit price of one litre or kilogram of output sold of cassava product by jth farmer

Q_j= Total output sold of cassava product by the jth normalized at hectare level.

P_i= Unit cost/price of a given input used by ith farmer to produce cassava product (Ushs/ha)
X_i = Quantity of input used in production of bioethanol (UShs/ha)

Normalization per hectare level was based on Katungi *et al*. (2011) and Tebeka *et al*. (2017). Total variable costs computed included all costs incurred in production of cassava such as costs of land clearing and land preparation, cost of purchase of inputs such as planting materials, planting costs, weeding, harvesting and transportation costs for both hired and family labour. For the category of farmers who bought chips for bioethanol production, the variable costs included cost of purchasing chips per kilogram which were computed and then normalized at hectare level. Transport costs to milling and processing facility were also computed. In addition, processing costs such as, peeling, drying and packaging costs, milling, fermentation, roasting and distillation costs were calculated for both farmers who bought chips and farmers who grew cassava for bioethanol production. Other costs computed included costs of yeast and cost of firewood used for distillation process, packaging, transportation and market dues for bioethanol. Revenues were then generated by multiplying the average price of one litre of bioethanol at market price at the time of data collection and the number of litres of bioethanol produced using quantity of chips purchased and normalized at hectare level.

Sensitivity analysis of the costs of cassava bioethanol production was conducted. From the reconnaissance visit to the farmers, the three most essential factors affecting bioethanol production were price of cassava chips, cost of roasting and cost of firewood. The influence of price of cassava chips, costs of roasting and costing of firewood on the gross profits were determined by creating four scenarios which included varying the costs by plus or minus 40% from the base figure taken as 0% which was the profit computed for each category from bioethanol category following Hanif *et al*. (2016). The values obtained were presented in an excel tornado plot.

To determine the factors influencing farmer decision to produce bioethanol, discrete choice model was considered as appropriate because of the discrete nature of cassava farmers' decisions. Therefore, qualitative choice models including linear probability, logit and probit models were considered the most suitable (Scott and Freese, 2006). Using binary models, the probability of a cassava farmer processing cassava into bioethanol is expressed as a function of the underlying predictor variables represented by a vector x. The outcomes of the models can be given a latent variable interpretation to provide a link with the linear regression model. Since the observed binary outcome is that a cassava farmer processed cassava into bioethanol, the underlying continuous unobservable or latent variable can be expressed using the following single index model:

$$y^* = x'\beta + \mu \qquad (1)$$

Although y^* is not observed, we can observe that

$$y = \begin{cases} 1, & y^* > 0 \\ 0, & y^* \leq 0 \end{cases} \qquad (2)$$

Therefore,

$$Pr(y = 1/x) = Pr(x'\beta + \mu > 0) = F(x'\beta) \qquad (3)$$

The linear probability model suffers from three important shortcomings: the error term μ is heteroscedastic and may possess elements of non-normality; and the predicted value of the dependent variable may not fall within the unit interval (Wooldridge, 2002). Whereas generalized least square models may solve the problem of heteroscedasticity, the problem of estimating parameters of a threshold decision model remains unresolved when truncating values of the dependent variable through logit analysis (Press and Wilson, 1978; Jones *et al*., 1989; Scott and Freese, 2006). The probit model overcomes these problems of the other models because of its ability to generate bounded probability estimates for each observation (Tambi, 1999). For this reason, we estimated a probit model in this study.

However, to produce bioethanol from cassava, farmers must first process cassava into dry chips. Depending on the utility generated from producing dry chips, farmers can choose to process cassava into dry chips and sell them if the dry chips maximize their utility (net returns). Similarly, if bioethanol production is more utility maximizing than selling dry chips, farmers are likely to produce bioethanol than selling dry chips. Therefore, the decision to produce bioethanol and sell cassava dry chips are linked thus creating a problem of endogeneity. As a result, a bivariate probit model was estimated because it solves the endogeneity problem by accounting for the correlation while testing for existence of correlation (Greene, 2003). The joint probability function for a farmer j of choosing to produce bioethanol given dry chips the same time $(Y_{1j} = Y_{2j} = 1)$ would be; at

$$\gamma_{sj} = p(Y_{1j} = 1 Y_{2j} = 1) = \int_{-\infty}^{\varepsilon_{1j}} \int_{-\infty}^{\varepsilon_{2j}}$$

$$\emptyset_2 (X_{1j}\beta_1, X_{2j}\beta_2, \rho) d\varepsilon_{1j} d\varepsilon_{2j}$$

$$= \emptyset_2(X_{1j}\beta_1 X_{2j}\beta_2) \qquad 5$$

The log-likelihood is then a sum across the four possible contracting variables (that is, four possible combinations of production of bioethanol $(Y_{1j} = Y_{2j} = 1)$ and no production of bioethanol $(Y_{1j} = Y_{2j} = 0)$ times their associated probabilities (Greene, 2003).

To estimate the bivariate probit model, the observed outcome equals 1 if farmer produces and markets bioethanol, zero otherwise, and equals 1 if a farmer produces and markets dry chips, zero otherwise. Production and marketing of bioethanol and dry chips are binary outcomes with the underlying continuous unobservable variables. In effect, there are two binary dependent variables namely; production and marketing of bioethanol and production and marketing of dry chips Y_i, j = 1, 2. These represent two interrelated decisions with correlated disturbances and allows the equations to be estimated simultaneously (Greene, 2003). Following Greene (2003), the bivariate probit model is joint model for two binary outcomes that generalizes the index function model from one latent variable to two latent variables that may be correlated and specified as;

$$y_{i1}^* = x_{i1}\beta_1 + e_1, \; ..$$

$$y_{i2}^* = x_{i2}\beta_2 + e_2,$$

Where the e_1 and e_2 are joint normal with means zero, variances one, and correlation ρ. Then y_j^* are unobservable and related to the binary dependent variables y_j by the following rule

$$y_1 = \begin{Bmatrix} 1 \; if \; y_2^* > 0 \\ 0 \; if y_2^* \leq 0 \end{Bmatrix} \quad y_2 = \begin{Bmatrix} 1 \; if \; y_2^* > 0 \\ 0 \; if y_2^* \leq 0 \end{Bmatrix}$$

This model collapses to two separate probit models for and when the error correlation ρ = 0. The error terms are normally distributed with a zero mean, variance equal to 1 and q denoting their covariance term

$$\begin{pmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \end{pmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & p \\ p & 1 \end{pmatrix} \right]$$

RESULTS AND DISCUSSION

Smallholder farmers' characteristics based on the major cassava products produced. Table 2 presents the characteristics of farmers based on the cassava products produced and marketed. The results show that individuals who produced and marketed bioethanol were more educated, involved in off farm work, used local cassava varieties and reported better road conditions than their counterparts who produced and marketed dry chips. Also, households who produced and marketed dry chips were more experienced in marketing chips and belonged to Pentecostal church in comparison to their counterparts.

Association between study variables for determining farmer decisions to produce bioethanol. Table 3 show the results of the Pearson correlation coefficients. The results suggest that female headed households, farmers who do not belong to the Pentecostal church, farmers who use better roads and grow improved varieties were more likely to produce and market bioethanol. On the other hand, being a Pentecostal Christian, experience in cassava growing, poor road conditions and growing improved variety were positively and significantly associated with the production and marketing of dry chips. In addition, there were significant correlations between various predictor variables for example marital status, experience, Total Livestock Units (TLU), and land size were found to be positively correlated with age. The results suggest that as farmers get older, they are more likely to get married, rear livestock and own more land. However, their variance inflation factors (vif) between the various predictor variables revealed absence of collinearity problem.

Table 1. Description of variables used to analyse the factors influencing farmer decisions to produce and market bioethanol

Variable	Description	Expected impact	
		D.C	Bio
Dry chips	1 if farmer produced dry chips from cassava, 0 otherwise	NA	-
Bioethanol	1 if farmer processed bioethanol from cassava,0 otherwise	-	NA
Age	Age of the household head in years	+	+
Sex	1 if Male, 0 Female	+	+
Marital status	1if respondent is married, 0 otherwise)	+	+
Education	1 highest level of education attained by household head, 0 otherwise	-	-
Religion	1if respondent is Pentecostal Christian, 0 otherwise	-+	-
Household size	Number of people in household at the time of interview	+	+
Experience	Farming experience of the household head (Years)	+	+
Land size	Land size owned (Acres)	-	+
Off-farm employment	1 if farmer is engaged in off-farm job, 0 otherwise	-	-
TLU	Total livestock units in each household	-	-
Membership to farmer group	1 if farmer belongs to group 0, Otherwise	+	+
Access to Credit	1 if farmer had access to credit, 0 otherwise	+	+
Distance to output market	Distance to output market (km)	-	-
Improved road condition	1 if the road condition is very good, 0 otherwise	+	+
Improved cassava variety	1 If variety planted is improved, 0 otherwise	+	-/+
Profitability of dry chips	1if dry chips production is profitable, 0 otherwise	+	+-
Profitability of Bioethanol	1if Bioethanol production is profitable, 0 otherwise	-+	+

(+) Represents a positive hypothesized impact of given variable on farmer's decision and (-) represents negative impact. NA (Not applicable); TLU as defined in Stock *et al*. (1991) (Cattle =0.7; calves =0.4; Goats =0.1; Sheep =0.1; Pigs= 0.2; chickens =0.01)

Table 2. Characteristics of farmers based on cassava products produced

Variable	Overall Sample	Dry chips	Bioethanol	T-test value/ Chi-square
Age(years)	39.88	41.73 (15.23)	39.24 (13.67)	-1.52
Household size	6.22	5.92 (2.27)	6.19 (2.084)	0.84
Experience(years)	17.41	19.69(13.55)	16.77 (12.10)	-1.97*
Land size(ha)	3.14	3.44 (3.66)	3.05 (1.701)	-1.15
Proportion under cassava(ha)	0.43	0.446 (0.28)	0.41 (0.246)	-1.4
Total Livestock Units	2.19	2.054 (2.23)	2.17 (1.94)	0.38
Distance to nearest market (Km)	2.75	2.776 (1.81)	2.69 (2.77)	-0.31
Improved Cassava variety (%)	34.00	23.44	51.06	-3.44***
Membership to farmer group (%)	70.00	68.75	62.38	0.32
Access to Credit (%)	57.00	60.94	51.06	0.93
Marital status (%)	84.00	83.00	86.00	0.52
Education (%)	83.00	70.31	89.11	3.26**
Pentecostal Christians (%)	10.00	27.00	1.00	-6.08***
Households participate in Off-farm work (%)	49.00	17.19	66.34	6.99***
Use Improved road (%)	58.00	44.00	66.00	2.90***
Male Headed households (%)	73.00	25.26	23.33	0.64

Note: Level of significance: *p < 0.05, **p < 0.01, ***p < 0.001.

Table 3. The association of the predictor variables for production and marketing of fresh tubers, bioethanol and dry chips, Pearson correlation coefficients

	D.C	Bio	Age	Gender	M.S	EDU	Religion	HHS	EXP	GRP	C.A	Out MKT	RD CN	OFF[-1]	TLU	Land size	PRPN-Cas		CAS V	Prof-Bio	Prof D.C
D.C	1.000																				
Bio	-0.437*	1.000																			
Age	0.069	-0.042	1.000																		
Gender	-0.035	-0.106*	0.021	1.000																	
M.S	0.082	-0.058	0.199***	0.234***	1.000																
EDU	-0.107*	0.0709	-0.339***		0.087	-0.253***		1.000													
Religion	0.226***	-0.379***		0.039	0.055	0.047	0.020	1.000													
HHS	-0.055	0.064	0.290***	-0.027	-0.169**	-0.050	0.065	1.000													
EXP	0.135*	-0.078	0.807***	0.167**	0.314***	-0.310***		0.016	0.221***	1.000											
GRP	-0.045	0.017	-0.106	-0.148*	0.031	-0.103	0.011	-0.125*	-0.114*	1.000											
C.A	-0.077	0.0297	-0.139	-0.021	-0.030	0.033	-0.014	-0.084	-0.186***		0.369***	1.000									
Out MKT	-0.005	-0.047	0.103	0.053	0.165**	-0.029	0.032	-0.003	0.159	-0.107	-0.176***		1.000								
RD CN	0.107*	-0.171**	0.007	0.040	0.037	-0.006	-0.0589	-0.0823	-0.0435	0.0537	0.0613	-0.105	1.000								
OFF-I	-0.199***		0.533***	-0.021	-0.028	0.018	0.054	-0.174***		0.032	0.029	0.044	-0.02	0.037	-0.156*	1.000					
TLU	-0.072	-0.045	0.172**	0.218***	-0.05	0.157*	0.2083***		0.342***	0.181***	-0.066	-0.036	0.038	-0.036	0.110	1.000					
Land size	0.065	-0.083	0.1736*	0.074	0.017	0.0262	0.2587*	0.211*	0.174*	-0.088	-0.007	0.056	0.1096	-0.007*	0.522***	1.000					
PRPN-C	0.065	-0.083	-0.114**	-0.059	0.029	0.062	-0.050	-0.155*	-0.088	0.037	0.053	-0.018	0.109	-0.106**	-0.185***		-0.362***		1.000		
Cas V	0.119*	-0.237***		-0.087	0.094	-0.06	-0.019	0.073	-0.044	-0.120*	-0.049	-0.066	0.022	0.0863	-0.136*	0.116	0.097	0.098	1.000		
Prof Bio	-0.190***		0.560***	-0.022	-0.003	-0.103	0.061	-0.276***		0.076	-0.056	0.067	0.042	0.292***	-0.070	-0.124*	0.073	-0.123*	-0.123	-0.069	1.000
Prof-D.C	0.359***	-0.234***		0.093	0.028	0.137*	0.037	0.265***	-0.012	0.111*	0.085	0.030	-0.166**	0.063	-0.009	-0.008	0.026	0.026	0.042	-0.063	1.0000

Note: Level of significance of Pearson correlation coefficient *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.
D.C-Dry chips, Bio-Bioethanol, M.S- Marital status of Household head, EDU-Education, HHS- Household size, EXP-Experience of Household head, GRP-Membership to farmer's, C.A Access to credit., Out MKT-Output Market, RD CN-Road condition, OFF-Income earned from off-farm work, TLU -Total Livestock Units, PRPN-C Proportion of land under cassava. Cas-V Improved cassava variety Profitability of bioethanol production

Profitability of bioethanol production. Table 4 presents the results of the production costs incurred for fresh tubers, dry chips and bioethanol. The results reveal that the highest production costs are incurred for fresh tubers, followed by bioethanol from cassava chips bought then by dry chips and least production costs are incurred by farmers who produce bioethanol from cassava grown at home. Specifically, weeding contributed the highest production costs for fresh tubers, dry chips and bioethanol produced by farmers who grow their own cassava followed by ploughing while transport of planting material contributed the least production costs for the three products. For bioethanol produced by farmers who buy cassava chips, the cost of purchase of cassava chips was the only single and the highest production cost incurred.

The processing and marketing costs of fresh tubers, dry chips and bioethanol. The results show that the processing costs were highest in bioethanol produced by farmers who grow their own cassava followed by dry chips and the least costs were incurred by farmers who buy chips for bioethanol production. There were no processing costs reported for fresh tubers. The processing costs for bioethanol from cassava grown were higher than the processing costs for cassava bought for bioethanol production. This is attributed to extra costs of peeling and drying incurred during processing of cassava grown. The results also showed that the marketing costs were highest in fresh tubers followed by bioethanol produced by farmers who grow own cassava for its production followed by dry chips and least marketing costs were incurred by farmers who buy cassava chips for bioethanol production. The high marketing costs of bioethanol could be attributed to the extra packaging costs, long distances to the market which is mainly in urban centres and market dues incurred during the marketing process.
Table 5 presents a summary of the production, processing and marketing costs as well as revenues for each of the three products including computations of gross margins and gross margin percentages. The results show that on average about 23 tonnes per hectare of fresh roots are produced by farmers in the three districts of northern Uganda. This is equivalent to about 8 tonnes of dry cassava chips per hectare indicating conversion ratio of 3 to 1 for fresh tubers and dry chips. The results further show that about 23 tonnes of fresh tubers per hectare produce about 3000 litres of bioethanol indicating an average production of 139 litres of bioethanol per one tonne of fresh cassava roots. At the time of data collection, on average farmers sold one kilogram of fresh tubers at 235 shillings, one kilogram of dry chips was 927 shillings and one litre of bioethanol was being sold at 4175 Uganda shillings per litre (1 US$=3364.65 Ugsh approximately). However, these prices vary greatly depending on season and availability of cassava.

The results indicated that households who bought chips for bioethanol production incurred much higher total variable costs than households who produced own cassava for sale as fresh tubers, dry chips or processed into bioethanol (Table 5). This is probably because most of the work is done by household labour and farmers have a tendency of undervaluing their cassava below the market price. Among the cassava farmers producing fresh tubers, dry chips and bioethanol from cassava grown by the farmers, the results showed that production costs were highest in fresh tubers followed by dry chips and bioethanol with the least production. This is probably because fresh tubers are perishable and considered of high value. It may also be because there are no additional costs such as processing costs incurred in production of fresh tubers.

Table 4. Summary of the production, processing and marketing costs of Fresh tubers, dry chips and bioethanol

Item description	Fresh tubers	(%)	Dry Chips	(%)	Bioethanol from Cassava Grown	(%)	Bioethanol from Cassava Bought	(%)
Quantity of dry cassava bought (kg)	N/A		N/A		N/A		7942.05	
Price per kilogram of Dry chips(Ugx/kg)	N/A		N/A		N/A		927	
Cost of purchasing dry chips (Ugx)							7,362,280	74.99
Bush clearing (Ugx)	106,846.60	6.89	102,566.48	5.2	109,247.58	2.53	N/A	
Ploughing(Ugx)	292,410.20	18.85	236,647.80	12	254,549.40	5.9	N/A	
Planting material(Ugx)	162,857.50	10.5	126,043.85	6.39	128,167.68	2.97	N/A	
Cutting and bagging of planting material(Ugx)	28,129.45	1.81	265,87.07	1.35	291,62.47	0.68	N/A	
Transport of planting material (Ugx)	21,834.35	1.41	245,81.58	1.25	26,418.51	0.61	N/A	
Planting (Ugx)	42,945.89	2.77	359,01.66	1.82	35,902.39	0.83	N/A	
Fertilizers	0	0	0	0	0	0	N/A	
Weeding (Ugx)	385,021.90	24.82	440,978.57	22.4	445,413.60	10.32		
Uprooting (Ugx)	134,125.30	8.65	166,455.66	8.44	108,545.64	2.51	N/A	
Packaging and transport home (Ugx)	86,656.87	5.59	65,321.67	3.31	70,321.75	1.63	N/A	
Total Production Costs (Ugx)	1,260,828.00	81.29	1,225,084.30	62.1	1,207,729.02	27.97	7,362,280	74.99
Processing Costs								
Peeling(Ugx)			313,312.88	15.9	588,121.28	13.62	N/A	N/A
Drying(Ugx)			164,741.93	8.35	216,741.56	5.02	N/A	N/A
Milling (Ugx)					201,003.47	4.66	135,559.32	1.38
Fermentation (Ugx)					241,535.04	5.59	303,530.07	3.09
Roasting (Ugx)					264,730.07	6.13	279,108.11	2.84

Distillation (Ugx)					320,943.82	7.43	313,996.63	3.2
Yeast (Ugx)					242,362.21	5.61	266,373.81	2.71
Firewood (Ugx)					325,121.62	7.53	342,779.65	3.49
Total Processing costs			478,054.81	24.2	2,400,559.07	55.6	1,641,347.59	16.72
Marketing Costs								
Packaging (Ugx)	100,682.71	6.49	87,406.61	4.43	341,092.14	7.9	408,195.62	4.16
Transport (Ugx)	143,880.94	9.28	134,374.58	6.81	231,638.81	5.36	256,430.58	2.61
Market Dues (Ugx)	45,644.60	2.94	47,570.71	2.41	136,639.11	3.16	150,020.61	1.53
Total marketing costs	290,208.25	18.71	269,351.90	13.7	709,370.06	16.43	814,646.81	8.3
Total processing and marketing costs	290,208.25	18.71	747,406.71	37.9	3,109,929.13	72.03	2,455,994.40	25.01

Source: Survey Data 2016; UGX- Uganda shillings; 1 USD = 3364.65 UGX

Table 5. Gross margin analysis of fresh tubers, dry chips and bioethanol

Item description	Fresh tubers	Dry chips	Bioethanol from cassava grown	Bioethanol from cassava bought
Revenues				
Quantity of fresh cassava (kg/Ha)	22,862.51	22,862.51	22,862.51	N/A
Quantity of Dry chips (kg/Ha)		7,942.05	7,942.05	7,942.05
Bioethanol yield (L/Ha)			3,171.75	3,502.34
Average price per litre or Kilogram (Ugx)	235.00	927.00	4,175.00	4,175.00
Total Revenues (TR)	5,372,689.85	7,362,280.35	13,242,056.25	14,622,269.50
Total Variable costs (TVC)				
Total Production Costs (Ugx)	1,260,828.07	1,225,084.34	1,207,729.02	7,362,280.35
Total Processing costs (Ugx)	0.00	478,054.81	2,400,559.07	1,641,347.59
Total marketing costs (Ugx)	290,208.25	269,351.90	709,370.06	814,646.81
Total Variable Costs (TVC) (Ugx)	1,551,036.32	1,972,491.05	4,317,658.15	9,818,274.74
Gross Margin (TR-TVC) (Ugx)	3,821,653.53	5,389,789.30	8,924,398.10	4,803,994.76
Gross Margin (%)	71.13	73.21	67.39	32.85

Source: Survey Data 2016; UGX- Uganda shillings, 1 USD = 3364.65 UGX

As indicated in Table 6, the results show that bioethanol generated the highest revenue followed by dry chips and fresh tubers. Farmers who produced bioethanol from cassava bought generated more revenues than farmers who grew cassava for bioethanol production. Bioethanol produced from cassava grown generated the highest gross margins followed by dry chips and bioethanol produced from cassava chips bought and fresh tubers generated the lowest gross contribution. Although bioethanol generated the highest revenues, bioethanol generally generated the least gross margin percentages of 67.39% while dry chips generated the highest gross margin of 73.21% and fresh tubers generated gross margin of 71.13%. Bioethanol produced from cassava grown generated higher gross margin percentage of 67.39% than for bioethanol produced by farmers who buy cassava chips which generated gross margin percentage of 32.85%.

Figure 3 presents the results from the sensitivity analysis to investigate the changes in production costs on the profitability of cassava bioethanol produced using cassava chips bought. The investigated elements included price of buying dry chips, cost of firewood and cost of roasting. The results reveal that a 40 % decrease in the price of cassava dry chips increases the gross profit of bioethanol by 61% from 4.8 to 7.75 million Uganda shillings but on the contrary increasing the price of dry chips by 40% reduces the gross profits of bioethanol by 61%. Similarly, reducing cost of roasting of fermented broth by 40% increases the gross profit of bioethanol by only 2.50% from 4.80 million Uganda shillings to 4.92 million Uganda shillings. Likewise, reducing the cost of firewood by 40% increased the profitability of bioethanol by 2.30% from 4.80 to 4.91 million Uganda shillings. The above results demonstrate that price of buying cassava chips has significant effect on the gross profits of bioethanol, unlike the cost of firewood and costs incurred during roasting of the fermented broth.

Figure 4 presents the outcomes of sensitivity analysis which investigated the effects of changes in production costs of some elements on the gross profits of bioethanol produced from cassava grown by farmers in their households. The elements investigated include cost of peeling cassava, cost of firewood and roasting of fermented broth. The results revealed that a 40% decrease in peeling cost increases gross profit of bioethanol by 2.80% from 8.9 to 9.15 million Uganda shillings. Similarly, reducing the cost of firewood by 40% increases the gross profits by 1.46% from 8.90 to 9.03 million Uganda shillings. Likewise, a 40% reduction in cost of roasting of fermented broth increases the gross profit of bioethanol by 1.46% from 8.90 to 9.03 million Uganda shillings.

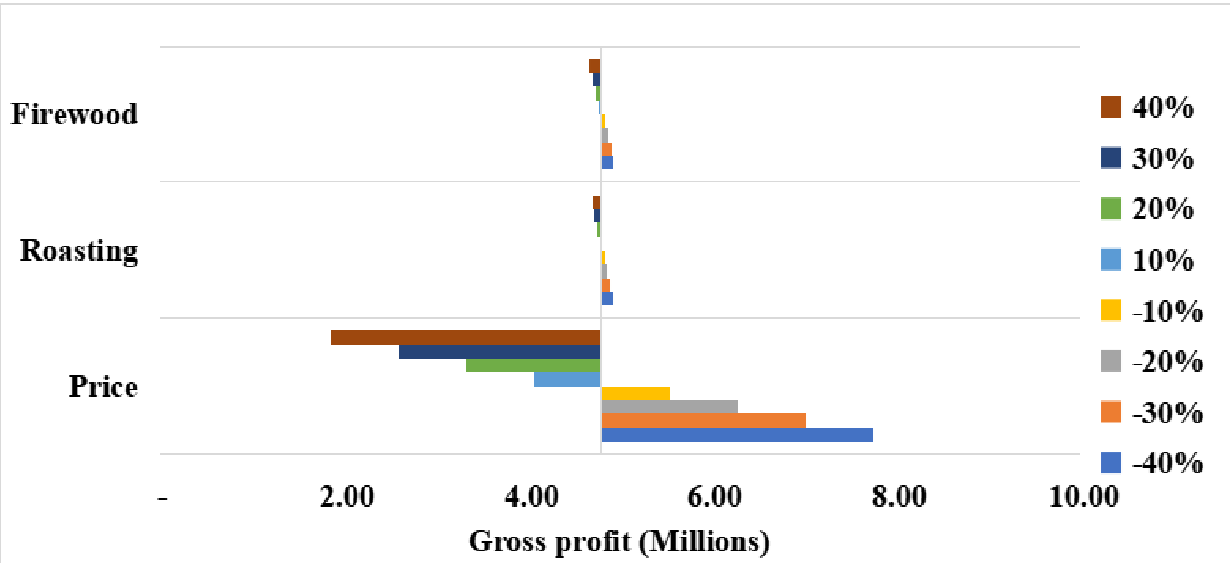


Figure 3. Sensitivity analysis of costs of cassava bioethanol production for farmers buying cassava chips

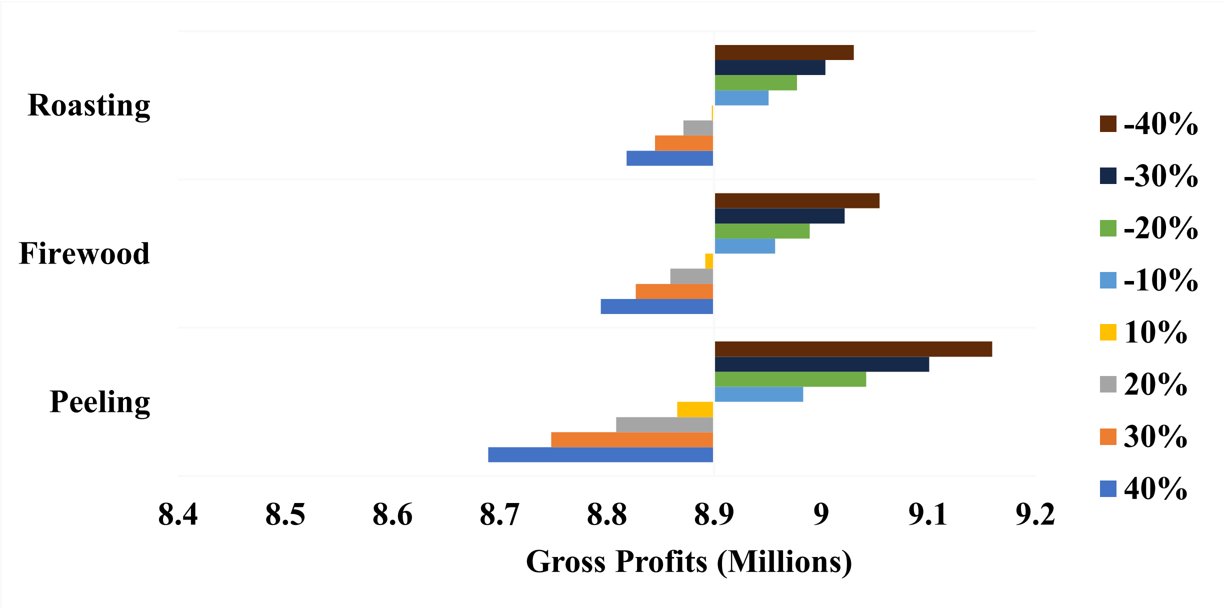


Figure 4. Sensitivity analysis of costs of cassava bioethanol production for farmers growing cassava

Factors influencing smallholder farmer's decisions to participate in bioethanol production

Table 6 presents results of the bivariate probit and probit model to determine the factors influencing farmer decisions to produce bioethanol. The results reveal that when bivariate model is estimated without including the profitability variables of bioethanol and dry chips, correlation coefficients between the errors (rho) was negative and significant at one percent. The inclusion of the profitability variables renders the correlation coefficients between the errors (rho) (0.416) insignificant. The result suggests that the profitability of producing and selling cassava dry chips is negatively associated with producing and selling bioethanol. In addition, results reveal that the decision to produce and sell bioethanol and the decision to produce, and market dry chips are jointly correlated.

The results also suggest that the inclusion of profit variable in estimation of a bivariate probit and probit models provides similar results. Indeed, as shown in Table 7 results from bivariate probit I and the Probit Model I are identical. Exclusion of the profitability variables for bioethanol and dry chips results into variables such as experience of the household head becoming significant for bioethanol while sex of the household head becomes insignificant. Variables such as use of improved cassava variety, improved road condition reduced in the level of significance after elimination of the profitability variable indicating that omission of variable has significant influence on goodness of fit of the model (Gujarati, 2004). In this section present the results from the models for which profit variables are included.

The results show that the age of the household head influenced farmers' decisions to produce bioethanol at $p<0.05$. For an additional increase in age of the household head, the likelihood of a farmer being involved in bioethanol production increases by 10.6%. Female headed households were more likely involved in bioethanol production than their male counterparts. Marital status of the household head also significantly influenced farmers' decisions to produce and market bioethanol at $p<0.01$. Married couples were more likely to produce bioethanol than their counterparts. The chances of married households being involved in bioethanol production was 87.3 %. Furthermore, belonging to a Pentecostal church negatively affects the production of bioethanol at $p<0.001$. Farmers who belong to a Pentecostal church were indeed less involved in bioethanol production.

In addition, land size and proportion of land under cassava positively influenced farmers' decisions to produce bioethanol at $p<0.01$. The higher the acreage of land and proportion of land under cassava planted, the more likely these households are to engage in production and marketing of bioethanol. In addition, farmers earning from an off-farm employment were more likely involved in bioethanol production than their counterparts and farmers growing local or native varieties are more likely using them for bioethanol production than farmers growing improved varieties at $p<0.001$. As expected, farmers earning profits from dry chips are less likely going to be involved in bioethanol production. Furthermore, profitability of bioethanol also greatly influenced farmers' decisions to produce bioethanol at $p<0.001$. The more profitable bioethanol is, the more likely the farmers were involved in its production. On the other hand, poor road conditions negatively affected the production of bioethanol.

Farmers in very poor road conditions are less likely involved in bioethanol production. The results show that being a Pentecostal Christian, land size, and condition of the road more likely positively influence smallholder farmers' decisions to produce dry chips while total livestock units, negatively influenced smallholders' decision to produce dry chips.

Table 6. Bivariate probit and probit estimates for smallholder farmers' decisions to produce bioethanol

Variables	Bivariate Probit I		Bivariate Probit II		Probit Model I		Probit Model II	
	Dry chips	Bioethanol	Dry Chips	Bioethanol	Dry chips	Bioethanol	Dry chips	Bioethanol
Age of the household head	-0.007(0.012)	0.106* (0.046)	-0.006(0.010)	0.031*(0.01)	-0.007(0.012)	0.092*(0.043)	-0.005 (0.012)	0.031*(0.014)
Sex of the household head	-0.122 (0.206)	-2.845***(0.854)	-0.166 (0.200)	-0.347(0.23)	-0.120(0.207)	-2.276**(0.857)	-0.177 (0.211)	-0.359(0.232)
Marital status of household head	-0.053 (0.136)	1.308**(0.422)	0.052 (0.130)	0.164 (0.15)	-0.054(0.137)	0.873* (0.437)	0.04(0.141)	0.113(0.157)
Education level of household head	-0.090 (0.124)	0.089(0.399)	-0.066(0.120)	0.140(0.14)	-0.090(0.125)	-0.047 (0.409)	-0.065 (0.123)	0.129(0.137)
Religion of the household head	0.262*(0.113)	-1.990**(0.655)	0.300** (0.100)	0.701***(0.130)	0.260*(0.112)	-1.659* (0.696)	0.304**(0.106)	-0.661***(0.125)
Household size	-0.041(0.045)	0.109(0.164)	-0.057 (0.050)	0.090(0.06)	-0.039(0.045)	0.052 (0.160)	-0.052 (0.045)	0.073(0.056)
Land size of the household	0.153**(0.051)	-0.213**(0.081)	0.163**(0.060)	-0.022(0.040)	0.150**(0.050)	- 0.212* (0.087)	0.153**(0.048)	-0.027 (0.041)
Proportion of land under cassava	0.704(0.397)	2.612**(1.010)	0.717(0.390)	-0.560 (0.41)	0.705(0.397)	3.083** (1.029)	0.705 (0.378)	-0.605 (0.411)
Off farm employment	-0.001 (0.002)	0.047***(0.013)	-0.002(0.000)	0.018*** (0.00)	-0.001(0.002)	0.036**(0.011)	-0.003(0.002)	0.018*** (0.003)
Total Livestock Units(TLU)	-0.154**(0.050)	-0.136(0.173)	-0.154**(0.050)	-0.019 (0.07)	-0.153**(0.050)	-0.076(0.162)	-0.159**(0.054)	-0.015 (0.070)

Experience in farming	0.020 (0.013)	-0.089(0.047)	0.024 (0.010)	-0.048* (0.02)	0.020(0.013)	-0.078 (0.043)	0.023(0.013)	-0.045** (0.017)
Membership to farmer group	-0.190 (0.215)	-0.594(0.760)	-0.058 (0.220)	-0.205 (0.24)	-0.184(0.214)	-0.476 (0.788)	-0.038 (0.218)	-0.116 (0.241)
Access to Credit	-0.259 (0.203)	-0.366 (0.572)	-0.200 (0.200)	0.119 (0.22)	-0.253 (0.202)	-0.214 (0.670	-0.220(0.201)	0.042 (0.219)
Distance to input/output market	-0.032 (0.032)	0.148(0.104)	-0.014(0.030)	-0.037 (0.04)	-0.0292(0.032)	0.089(0.104)	-0.013 (0.033)	-0.041 (0.041)
Improved road condition to nearest market	0.189* (0.090)	-0.857**(0.296)	0.168 (0.090)	-0.217(0.12)	0.1192* (0.090)	-0.866**(0.318)	0.168 (0.090)	-0.217(0.115)
Improved cassava variety grown	0.303(0.187)	-2.264***(0.580)	0.285 (0.190)	-0.519* (0.22)	0.3010(0.187)	-2.222***(0.585)	0.296 (0.186)	-0.568*(0.225)
Profitability of bioethanol	-0.000(0.000)	0.000***(0.000)			-0.000(0.000)	0.000***(0.000)		
Profitability of Dry chips	0.000(0.000)	-0.000***(0.000)			0.000(0.000)	-0.000***(0.000)		
Constant	-0.837(0.907)	4.220(3.302)	-1.450 (0.89)	1.362 (0.96)	-0.858(0.898)	5.122 (3.192)	-1.460 (0.882)	1.618 (0.969)
Rho	-0.579 (0.416)	-0.651 (0.086)						
$Chi^2(1)$	1.932	26.8602						
R^2				0.2086	0.9207	0.1434	0.4108	
Prob chi^2	0.164	0.0000	0.0005	0.0009	0.0009	0.0000		
Log likelihood	-137.913	-217.61102	-125.638	-127.159		-94.479		
n	237	237	237	237	237	237		
Wald(X2)(36)	92.098	Wald(X2)(32) 131.55	44.36	42.520	39.57	81.50		

All numbers shown in parentheses are robust standard errors.. *** p < 0.01, ** p < 0.05, * p <0.1 represent statistical significance at the 1%, 5%, and 10% alpha levels

DISCUSSION

The main objective of the study was to examine why bioethanol production from cassava is low in Uganda. To achieve this objective, the paper examined three research questions (1) Are smallholder farmers making profits from the current cassava bioethanol production? (2) Is selling dry cassava chips and fresh cassava tubers more profitable than selling bioethanol produced from cassava?, and (3) What factors drive rural households to produce bioethanol from cassava?

The results from the study reveal that small scale farmers are making profits from small scale bioethanol production which is consistent with the results from a study by Ogbonna and Okoli (2013) which demonstrated that small scale bioethanol production is profitable. The results also revealed that producing bioethanol from cassava grown at home is more profitable that bioethanol produced from dry chips bought because of the costs of dry chips is high. Indeed, the price of dry chips was found to have a significant effect on the gross margins of bioethanol for farmers producing bioethanol from cassava chips bought. Price volatility on the other hand, contributes to high cost of production from farmers buying chips consequently leading to reduced profits.

In addition, the high prices of cassava dry chips is attributed to low cassava production in Uganda which is associated with to re-occurrence and spread of Cassava Brown Streak Disease (CBSD) (Alicai *et al.,* 2007). Because of the CBSD, Uganda has annual net deficit of cassava and cassava derived products ranging from 70,000 MT to 900,000 MT (fresh root equivalent) (Kilimo-Trust, 2017). With these deficit and high price of cassava chips, extraction of bioethanol from cassava can only be achieved in Uganda through: (i) boosting production and productivity of cassava, and (ii) increasing returns from bioethanol production.

Boosting cassava production and productivity can only be achieved by improving agronomic practices and promoting improved cassava varieties that are resistant to CBSD such as NAROCass 1 & 2. Indeed, results from this study revealed that the higher the proportion of land under cassava, the higher the likelihood of a farmer engaging in the production of bioethanol. Similarly, the results show that farmers who grow improved varieties are more likely to produce and sell bioethanol. This is because expanding land area under cassava and promoting improved cassava varieties that resistant to disease would lead to glut supply and to offset losses, and as such farmers get involved in production of bioethanol (Naziri *et al.,* 2014). The glut supply means reduction in prices of cassava chips and roots which would make selling cassava chips less profitable. Extraction of bioethanol from cassava would therefore play significant role raising the value of cassava, sustaining household income and enhancing adoption of improved cassava technologies thus leading to significant increase in both yields and incomes which is key to poverty reduction (Cotula *et al.,* 2008).

As highlighted above, in addition to boosting production and productivity of cassava, there is need to increase the returns from bioethanol production by reducing the costs of processing bioethanol and expansion of the market opportunities through extra value addition and packaging. The recent outbreak of the Corona virus is such opportunity that raised the value of producing bioethanol from cassava. Globally many breweries and distilleries either shifted or diversified into production of the hand sanitizers which contains 70% bioethanol to sustain revenues (Thomson and Bullied, 2020). In Uganda, initially, there were only two companies producing sanitizers. However, with COVID 19 and declaration of tax exemption to transform ethanol to sanitizers about 48 companies joined the sanitizer production. However, only 10% of ethanol is produced in Uganda and of the 10%, over 90% of the ethanol is produced by small scale farmers using rudimentary tools. Of 90% of the farmers, 85% of these small-scale farmers are cassava farmers who produce only 11% of the ethanol from cassava (Mutyaba *et al.,* 2016; Nakabonge *et al.,* 2017). Therefore, promoting extraction of bioethanol production from cassava requires significant investment to establish bioethanol plants to extract the ethanol from cassava.

Results from this paper reveal that the use of rudimentary tools in processing of cassava to bioethanol reduces the profitability of bioethanol. This suggests that, increasing bioethanol production from cassava requires improved labour-saving technologies with very high processing power. In addition, the use of modern bioethanol processing technologies would help address the religious and social concerns that have negatively considered bioethanol production as evil. As the results from this study reveal being a Pentecostal Christian negatively affected production of bioethanol. Focusing on transforming individual farmers processing bioethanol into medium-scale industrial cassava processing units would address social factors like religion which impede bioethanol production. Evidence show that organizing social groups in Thailand by supporting them to form small and medium enterprises to produce high quality chips for bioethanol production increased farm incomes by 300% Graffham *et al*. (2017)

CONCLUSIONS AND RECOMMENDATION

The objective of this study was to assess why production of bioethanol from cassava is low in Uganda considering that it most efficient in production of bioethanol than any other crops used in Uganda. The results reveal that the low production of bioethanol from cassava is a result of the fact that: (1) there is low production arising from the growing local varieties that are susceptible to diseases moreover on small acreage; (ii) the technology used is rudimentary and less efficient leading to higher cost of production and generally less attractive; and (iii) the social cultural factors such religious beliefs that view bioethanol production as un Christian have negatively affected the extraction of bioethanol from cassava. To promote the extraction of bioethanol from Cassava in Uganda; we recommend increasing production of cassava and high-quality cassava chips to reduce the cost of bioethanol production and increase the gross margins and modernizing the cassava bioethanol extraction process. This will require strengthening and organizing farmer organizations and supporting them to produce high quality cassava chips for bioethanol production.

ACKNOWLEDGEMENT

This publication has been made possible through financial support provided by Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) under the Cassava Community Action Research Programme (CARP) (RUFORUM Grant No. RU 2014 CARP 04).

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Abass, A., Mlingi, N., Ranaivoson, R. and Zulu, M. (n.d.). Potential for commercial production and marketing of cassava : Experiences from the small-scale cassava processing project in East and Southern Africa.

Adiotomre, K. O. 2015. Production of bioethanol as an alternative source of fuel using cassava and yam peels as raw materials. *Int. J. Innov. Sci. Eng. Technol. Res* 3 (2): 28-44.

Alicai, T., Omongo, C. A., Maruthi, M. N., Hillocks, R., Baguma, Y., Kawuki, R., Bua, A., Otim-Nape, G. W. and Colvin, J. 2007. Re-emergence of Cassava Brown Streak Disease in Uganda. *Plant Disease* 91 (1): 24-29. https://doi.org/10.1094/PD-91-0024

Balat, M. and Balat, H. 2009. Recent trends in global production and utilization of bio-ethanol fuel. *Applied Energy* 86 (11): 2273–2282. https://doi.org/10.1016/j.apenergy.2009.03.015

Cotula, L., Dyer, N. and Vermeulen, S. 2008. Fuelling exclusion. The biofuels boom and poor people's access to land. IIED, London, 72pp.

Ejigu, M. 2008, May. Toward energy and livelihoods security in Africa: Smallholder production and processing of bioenergy as a strategy. *Natural Resources Forum* 32 (2):152-162).

Food and Agriculture Organisation (FAO). 2011. Global food losses and food waste - Extent, causes and prevention. In Save Food: An initiative on food loss and waste reduction. https://doi.org/10.1098/rstb.2010.0126

Food and Agriculture Organisation (FAO). 2017. Food and Agriculture driving action across the

2030 Agenda for Sustainable Development. 40. http://www.fao.org/3/a-i7454e.pdf

Graffham, A. and Kalunda, P. 2000. Starch-based products : An assessment of the industrial potential for.

Greene, W. H. 2003. Econometric analysis. Senior Media Project Manager : Victoria Anderson Production Editor : Michael Reynolds.

Hanif, M., Mahlia, T.M.I., Aditiya, H.B. and Chong, W.T. 2016. Techno-economic and environmental assessment of bioethanol production from high starch and root yield Sri Kanji 1 cassava in Malaysia. *Energy Reports* 2: 246-253.

IEA. 2017. International Energy Outlook 2017 Overview. U.S. Energy Information Administration, IEO2017(2017), 143. https://doi.org/www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf

Jakrawatana, N., Pingmuangleka, P. and Gheewala, S. H. 2016. Material flow management and cleaner production of cassava processing for future food, feed and fuel in Thailand. *Journal of Cleaner Production* 134 (Part B): 633–641. https://doi.org/10.1016/j.jclepro.2015.06.139

Katungi, E., Karanja, D., Wozemba, D., Mutuoki, T. and Rubyogo, J. C. 2011. A cost-benefit analysis of farmer based seed production for common bean in Kenya. *African Crop Science Journal* 19 (4): 409–415.

Kleih, U., Phillips, D., Jagwe, J. and Kirya, M. 2012. Cassava Market and Value Chain Analysis Uganda Case Study Final Report (Anonymised version) July 2012. July.

Kristensen, S. B. P., Birch-Thomsen, T., Rasmussen, K., Rasmussen, L. V. and Traoré, O. 2014. Cassava as an energy crop: A case study of the potential for an expansion of cassava cultivation for bioethanol production in southern mali. *Renewable Energy* 66: 381–390. https://doi.org/10.1016/j.renene.2013.12.021

Kueneman, E., Raswant, V., Lutaladio, N. and Cooke, R. 2012. Global consultation on cassava as a potential bioenergy crop. IFAD, Accra.

Liu, B., Wang, F., Zhang, B. and Bi, J. 2013. Energy balance and GHG emissions of cassava-based fuel ethanol using different planting modes in China. *Energy Policy* 56: 210–220. https://doi.org/10.1016/j.enpol.2012.12.052

Malinvaud, E. 1989. Profitability and factor demands under uncertainty. *De Economist* 137 (1): 91–92.

Mathews, J. A. 2012. Opinion: is growing biofuel crops a crime against humanity? *Biofuels, Bioproducts and Biorefining* 6 (3): 246–256. https://doi.org/10.1002/bbb

Mitchell, D. 2008. A note on rising food prices. World Bank Development Prospects Group, July, 21. https://doi.org/10.2139/ssrn.1233058

Monbiot, G. 2007. An agricultural crime against humanity. *The Guardian*. pp.6–9.

Mukasa, S. (n.d.). Abstract résumé advances in cassava research in management of Cassava Brown Streak Virus disease in Uganda. 1467-1483.

Mutyaba, C., Lubinga, M. H., Ogwal, R. O. and Tumwesigye, S. 2016. The role of institutions as actors influencing Uganda' s cassava sector. 117(1): 113–123.

Nakabonge, G., Samukoya, C. and Baguma, Y. 2017. Local varieties of cassava: conservation, cultivation and use in Uganda. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-017-9997-6

Naziri, D., Quaye, W., Siwoku, B., Wanlapatit, S., Viet, T. and Bennett, B. 2014. The diversity of postharvest losses in cassava value chains in selected developing countries. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 115 (2): 111–123.

Nguyen, T. N. L. and Nguyen, V. C. 2020. The determinants of profitability in listed enterprises: A study from vietnamese stock exchange. *Journal of Asian Finance, Economics and Business* 7(1): 47–58. https://doi.org/10.13106/jafeb.2020.vol7.no1.47

Nuwamanya, E., Chiwona-Karltun, L., Kawuki, R. S. and Baguma, Y. 2012. Bio-ethanol production from non-food parts of cassava (*Manihot esculenta Crantz*). *Ambio* 41 (3): 262–270. https://doi.org/10.1007/s13280-011-0183-z

Ohimain, E. 2015. Smallholder bioethanol production from cassava feedstock under rural Nigerian settings. *Energy Sources Part B-Economics Planning and Policy* 10 (3): 233–

240. https://doi.org/10.1080/15567249.2010.549903

Oketch, B. 2016. Cassava production rises as farmers benefit from ethanol plant. The Daily Monitor, 8–10.

Report, C. 2010. Market assessment and baseline study of January.

Republic, T. H. E. (n.d.). The Potential of Bio-fuel in Uganda.

Rushton, J. 2009. The economics of animal health. 1–384.

Schmitz, M. and Moleva, P. 2013. Determinants for the level and volatility of agricultural commodity prices on international markets: Are biofuels responsible for price volatility and food.

Tebeka, Y.A., Katungi, E., Rubyogo, J.C., Sserunkuuma, D. and Kidane, T. 2017. Economic performance of community based bean seed production and marketing in the central rift valley of Ethiopia. *African Crop Science Journal* 25 (2): 189-205.

Tenenbaum, D. J. 2008. Food vs. fuel diversion of crops could cause more hunger. *Environmental Health Perspectives* 116 (6): 254–257. https://doi.org/10.1289/ehp.116-a254

Thatoi, H., Dash, P. K., Mohapatra, S. and Swain, M. R. 2016. Bioethanol production from tuber crops using fermentation technology: a review. *International Journal of Sustainable Energy* 35 (5): 443–468. https://doi.org/10.1080/14786451.2014.918616

UBOS. 2010. Uganda Census of Agriculture 2008/2009, Volume IV: Crop Area and Production Report: Vol. IV. www.ubos.org

Valin, H., Sands, R. D., van der Mensbrugghe, D., Nelson, G. C., Ahammad, H., Blanc, E., Bodirsky, B., Fujimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Mason-D'Croz, D., Paltsev, S., Rolinski, S., Tabeau, A., van Meijl, H., von Lampe, M. and Willenbockel, D. 2014. The future of food demand: Understanding differences in global economic models. *Agricultural Economics* 45 (1): 51–67.https://doi.org/10.1002/macp.201500188

World Bank. 2016. The Uganda Poverty Assessment Report: Farms, cities and good fortune : assessing poverty reduction in Uganda from 2006 to 2013. World Bank.

Zhang, C., Han, W. and Jing, X. 2003. Life cycle economic analysis of fuel ethanol derived from cassava in southwest China. 7: 353–366. https://doi.org/10.1016/S1364-0321(03)00057-1

Ziegler, J., Gloay, C., Mahon, C. and Way, S.-A. 2011. The Fight for the Right to Food: Lessons learned.

African Journal of Rural Development, Vol 7(1) January-April 2022: pp.111-132. ISSN 2415-2838

Rainwater harvesting technologies: Adoption, maintenance, and limitations among smallholder farmers in drought prone areas of Uganda

D. MFITUMUKIZA, [1,2,*] B. BARASA,[3] H. SSEVIIRI,[1] A. NYARWAYA,[2] G. MWESIGWA YOFESI[2] and N. KIGGUNDU[4]

[1]Department of Geography Geo-informatics and Climatic Sciences, Makerere University, P.O. Box 7062, Kampala, Uganda

[2]Stewardship Institute of Environment and Natural Resources (SIENR) P.O. Box 7298, Kampala, Uganda

[3] Department of Geography and Social Studies, Kyambogo University, P.O. Box 1, Kyambogo, Kampala, Uganda

[4]Department of Agricultural and Biosystems Engineering, Makerere University, P.O. Box 7062, Kampala, Uganda

Corresponding Author: dmfitumukiza@gmail.com

ABSTRACT

Despite the devastating effects of drought on agriculture-dependent lives and livelihoods, there is a very low level of understanding and use of available water stress management technologies such as rainwater harvesting (RWH). This study characterized RWH technologies used by smallholder farmers in drought-prone areas of Uganda to establish the limitations to their optimal use. A cross-sectional household survey involving a mixture of stratified random and purposive sampling was carried out. A total of 480 smallholder farmers utilizing RWH technologies were selected and interviewed using a semi-structured questionnaire. Data were analysed using descriptive statistics, signed-rank sum test, and a logistic regression model. Results show that plastic containers, metallic drums, metallic tanks, concrete ferrocement tanks, ponds, clay pots, valley tanks, and valley dams are the most used technologies. Most RWH technologies used roof surfaces at the catchment stage with gutters and pipes conveying water into the collection facilities. The RWH technologies are largely used for domestic and production purposes. The use is mainly influenced by livelihood dependence on livestock, farmer's age, and household size. Decisions for use of RWH systems largely (60%) depend on indigenous knowledge and experiences. Farmers perceived the low capacity of RWH systems, contamination of water sources, leaks, high cleaning intensity, seepage, and siltation as the major limitations to the utilization of RWH technologies. Therefore, innovations in knowledge, practice, and policy to enhance RWH technologies' capacity are needed. Such efforts should integrate scientific information with locally existing RWH management systems amongst the farmers.

Keywords: Climate change, livelihood, rain-fed agriculture, sub-Saharan Africa

RÉSUMÉ

Malgré les effets dévastateurs de la sécheresse sur les vies et les moyens de subsistance qui dépendent de l'agriculture, le niveau de compréhension et d'utilisation des technologies disponibles de gestion du stress hydrique telles que la collecte des eaux de pluie (CEP) est très faible. Cette étude a caractérisé les technologies « CEP » utilisées par les petits exploitants agricoles dans les zones vulnérables à la sécheresse de l'Ouganda pour établir les limites de leur utilisation optimale. Une enquête transversale auprès des ménages impliquant un mélange d'échantillonnage stratifié aléatoire et raisonné a été réalisée. Au total, 480 petits exploitants

Cite as: Mfitumukiza, D., Barasa, B., Sseviiri, H., Nyarwaya, A., Mwesigwa, G.Y. and Kiggundu, N. 2022. Rainwater harvesting technologies: Adoption, maintenance, and limitations among smallholder farmers in drought prone areas of Uganda. *African Journal of Rural Development* 7 (1): 111-132.

Recieved: 10 July 2020
Accepted: 30 December 2021
Published: 30 April 2022

agricoles utilisant des technologies de de CEP ont été sélectionnés et interrogés à l'aide d'un questionnaire semi-structuré. Les données ont été analysées à l'aide de statistiques descriptives, d'un test de somme des rangs signés et d'un modèle de régression logistique. Les résultats montrent que les conteneurs en plastique, les fûts métalliques, les réservoirs métalliques, les réservoirs en béton de ferrociment, les étangs, les pots en argile, les réservoirs de vallée et les barrages de vallée sont les technologies les plus utilisées. La plupart des technologies de CEP utilisaient des surfaces de toit au niveau du captage avec des gouttières et des tuyaux acheminant l'eau vers les installations de collecte. Les technologies de CEP sont largement utilisées à des fins domestiques et de production. L'utilisation est principalement influencée par la dépendance des moyens de subsistance à l'égard du bétail, l'âge de l'agriculteur et la taille du ménage. Les décisions d'utilisation des systèmes de CEP dépendent en grande partie (60 %) des connaissances et expériences indigènes. Les agriculteurs ont perçu la faible capacité des systèmes RWH, la contamination des sources d'eau, les fuites, la forte intensité de nettoyage, les infiltrations et l'envasement comme les principales limites à l'utilisation des technologies de CEP. Par conséquent, des innovations dans les connaissances, les pratiques et les politiques pour améliorer la capacité des technologies de CEP sont nécessaires. De tels efforts devraient intégrer les informations scientifiques aux systèmes de gestion de CEP existants localement parmi les agriculteurs.

Mots-clés: Changement Climatique, Moyens de subsistance, Agriculture pluviale, Afrique Subsaharienne

INTRODUCTION

Agriculture is a source of livelihood for more than 70% of the world's population (Muyanga and Jayne, 2014). Most of this population are smallholder farmers (Samberg *et al.,* 2016). Globally, about 500 million people directly depend on smallholder farming systems, representing 85% of the world's farms (Harvey *et al*., 2014). On average, the farmers operate on two hectares (Graeub *et al.,* 2016; Lowder *et al*., 2016). In Africa, smallholder farming contributes 20-60% of each country's GDP and employs two-thirds of the actively working population (Kilimani *et al.,* 2016). Similarly, Smallholder agriculture is vital to development in Uganda, with about 75% of the population directly depending on it (Wiggins and Sharada, 2013; AGRA, 2017).

Changes in climatic conditions including increased frequency and intensity of droughts have continued to negatively impact smallholder farming systems in Africa (Eakin *et al.,* 2014; Antwi-Agyei *et al.,* 2015; Giordano and Bassini, 2019). Drought incidences have resulted in increased water scarcity hence affecting agricultural production, mainly because of farmers' constrained preventive and adaptive capacity (Niang *et al.,* 2014; Ayanlade *et al.,* 2018). Smallholder farming is mostly carried out under rain-fed conditions with very limited use of irrigation (Mwangi and Kariuki, 2015; Moswetsi *et al.,* 2017).

Studies show that dependency on rain-fed agriculture for food and income is the major constraint to coping with drought-induced water stress among rural communities in Africa (Rankoana, 2016; Ubisi *et al.,* 2017). Less than 6% of the total area in Africa is under irrigation making the remaining cultivable land under rain-fed farming (Harris and Orr, 2014). As a result, the farmers continue to be susceptible to the impacts of dry spells and droughts, most especially in arid and semi-arid areas.

The complex dynamics of water stress associated with temperature and rainfall variability require innovative strategies to sustain smallholder agricultural production and livelihoods (Chivenge *et al.,* 2015). Numerous water management practices including; dam construction, desalination of salty water, installation of water-saving irrigation technologies and drainage networks, wastewater recycling and rainwater harvesting have been used to counter the problem of water stress in Africa (Kharraz *et al.,* 2012;

Brauman e*t al.,* 2013; Kummu *et al.,* 2016). It is, nevertheless, not known why there is still an extremely low level of use of such technologies and practices.

Although boosting agricultural production requires major water investments, the high yield gaps in the arid and semi-arid areas are not absolutely due to a lack of water but rather due to insufficient management (Rockström *et al.,* 2010; Foley *et al.,* 2011). For arid and semi-arid areas, a key strategy is to minimise the dry spell-induced livestock and crop failures, which requires, among others, emphasis on water harvesting systems for supplemental irrigation (Kimera, 2018; Kumar *et al.,* 2019). There is, however, inadequate research to inform practice on water harvesting for agricultural production among smallholder farmers. This inadequacy poses a limitation to options for managing the ever-increasing water stress problems in areas experiencing erratic rainfall patterns, but with potential for rainwater harvesting.

Rainwater harvesting (RWH) is one of the recognised practices to cope with and adapt to water stress in agricultural production (Assefa *et al.,* 2016). For example, harvesting 15% of rainwater in Africa would not only meet the continent's agricultural water needs but also provide water for other uses (Critchley and Gowing 2012). Rainwater harvesting (RWH) involves practices that aid the collection and storage of rainwater/ runoffs for domestic, agricultural, industrial and environmental uses (Rockstrom and Baron, 2003; Recha *et al.,* 2015).

Rainwater harvesting (RWH) catchment systems can be categorized as ex-situ or in-situ with four basic components including catchment or collection area, runoff conveyance, storage and an application area. Ex-situ systems collect water from rooftops, land surfaces, steep slopes, road surfaces, and rock catchments and are stored in tanks. In-situ technologies involve strategies undertaken through soil management practices to improve rainfall infiltration and reduction of surface runoff (Kiggundu *et al.,* 2018). These systems involve rainwater harvesting methods such as direct runoff concentration in the soil profile for direct crop uptake or approaches that support the collection and storage of rainwater in structures such as sub-surface, surface, small dams and ponds for future uses (Pachpute *et al.,* 2009). The use of a particular system and method is dependent on a combination of factors prevailing in a given location. In-situ RWH systems, for example, are more likely to be used by smallholder farmers because they require small investment capital since most systems are implemented on small scale (Kiggundu *et al.,* 2018). It is critical, therefore, that rainwater management efforts are well supported by context-specific studies to continuously ascertain the provision of actionable information to enhance decision-making for use of particular methods and technologies.

The importance of RWH technologies for smallholder farming livelihoods is well acknowledged (Yosef and Asmamaw, 2015; Taffere *et al.,* 2016; Londra *et al.,* 2018). For example, it has been reported that the collection and storage of rainwater in structures such as dams and ponds in combination with soil nutrient and crop management practices improve crop productivity (Pachpute *et al.,* 2009). Despite the recognised importance and potential of RWH in improving agriculture dependant lives and livelihoods, the rate of use of associated technologies is very low in the developing world (Bandiera and Rasul, 2006).

Some studies show that the low level of use of technology for agriculture-dependent communities is associated with factors such as farmer and farm household characteristics, biophysical conditions, financial and management practices as well as other exogenous factors beyond the control of the farmer (Yigezu *et al.,* 2018). Nevertheless, several aspects of technology use in agriculture, especially in Africa remain poorly understood (Worku, 2019). This is particularly so for smallholder farming systems in communities and countries where livelihood is predominantly dependent on agriculture.

Overall, there has been very minimal attention given to the location-specific understanding of RWH and associated technologies among smallholder farmers in drought-prone areas (Nnaji, 2019; Oremo *et al.,* 2019). There is particularly very limited understanding of location contextualised features of RWH technologies, their experiences and perceptions amongst smallholder farmers (Brauman *et al.,* 2013). Such understanding is needed to foster targeted decision-making processes aimed at alleviating the cost of drought both at micro and macro levels (Brauman *et al*., 2013; Kilimani *et al.,* 2016). Towards this end, this study seeks to characterize the various RWH technologies used in drought-prone areas of Uganda and establish the factors promoting and/or limiting their use among smallholder farmers. The study addresses the following questions in particular: i) What are the characteristics of the RWH technologies used by smallholder farmers as a coping response to drought? ii) What are the household level determinants for the adoption of RWH technologies? and iii) What are the limitations for optimal use of RWH technologies by farmers to cope with drought?

METHODOLOGY

Study area description. The study was conducted in southwestern, central and mid-western Uganda, covering nine districts: Hoima, Isingiro, Kiboga, Luweero, Masaka, Mubende, Nakaseke, Nakasongola and Sembabule (Figure 1). The main consideration for selecting the districts was their proneness to drought and their characteristic erratic rainfall distribution in space and time (Zziwa *et al.,* 2012; Nimusiima *et al*., 2013; Twongyirwe *et al*., 2019; Kakeeto *et al.,* 2019; Nakabugo *et al*., 2019). Rainfall in the study area is highly variable and sporadic with mean annual rainfall ranging between 500 mm and 1600 mm (Makuma-Massa *et al.,* 2017; Turyagyenda *et al.,* 2013). Generally, rains are usually expected from March to April (Long rains) and September to November (Short rains) of each seasonal calendar year. However, this has changed in the recent past where variability has increased significantly characterised by a shift in and shortening of growing seasons associated with more prolonged dry spells and droughts. The average temperatures range from 25 °C to 30 °C.

The area comprises an undulating landscape with a continuum of plains, hills and valleys associated with seasonal streams that often dry up once the rains have ceased hence leading to water scarcity (Mugerwa *et al.,* 2014). During water shortages associated with droughts and erratic rainfall, some households resort to migration with animal herds in search of water as well as engaging in off-farm activities. Water resources in the area include boreholes, multi-purpose valley tanks, dams and ponds that are non-uniformly distributed and under different ownership arrangements (Mugerwa *et al.,* 2014). The uneven distribution of water resources in the area undermines the livelihoods of the agro-pastoral households that predominate the area (Nsubuga *et al.,* 2014). Moreover, some of the land used and/or owned by the smallholder farmers in the area is under land tenures such as the customary system, which constrains equitably and gender-inclusive ownership and use (Vanlauwe *et al.,* 2014).

Agriculture is the main economic activity for most of the households in the study area. The subsistence of rain-fed crop growing and livestock rearing characterize most of the landscape. The key crops grown include maize, bananas, coffee, beans, cassava, etc. Livestock includes cattle, goats, sheep, pigs and poultry, among others. The secondary sources of income include fishing, formal employment, and small-scale businesses.

Data collection. The rainwater harvesting technologies considered in this study included jars, plastic tanks, metallic tanks, clay pots, industrial drums (metallic), concrete ferrocement tanks, 'jerrycans', valley tanks, valley dams and ponds. A detailed description of the RWH technologies is provided in Table 1.

[1]Customary tenure system is where the clan and other chiefs exercise control over land under family ownership as well as over land subject to collective rights (Van Leeuwen, 2014).

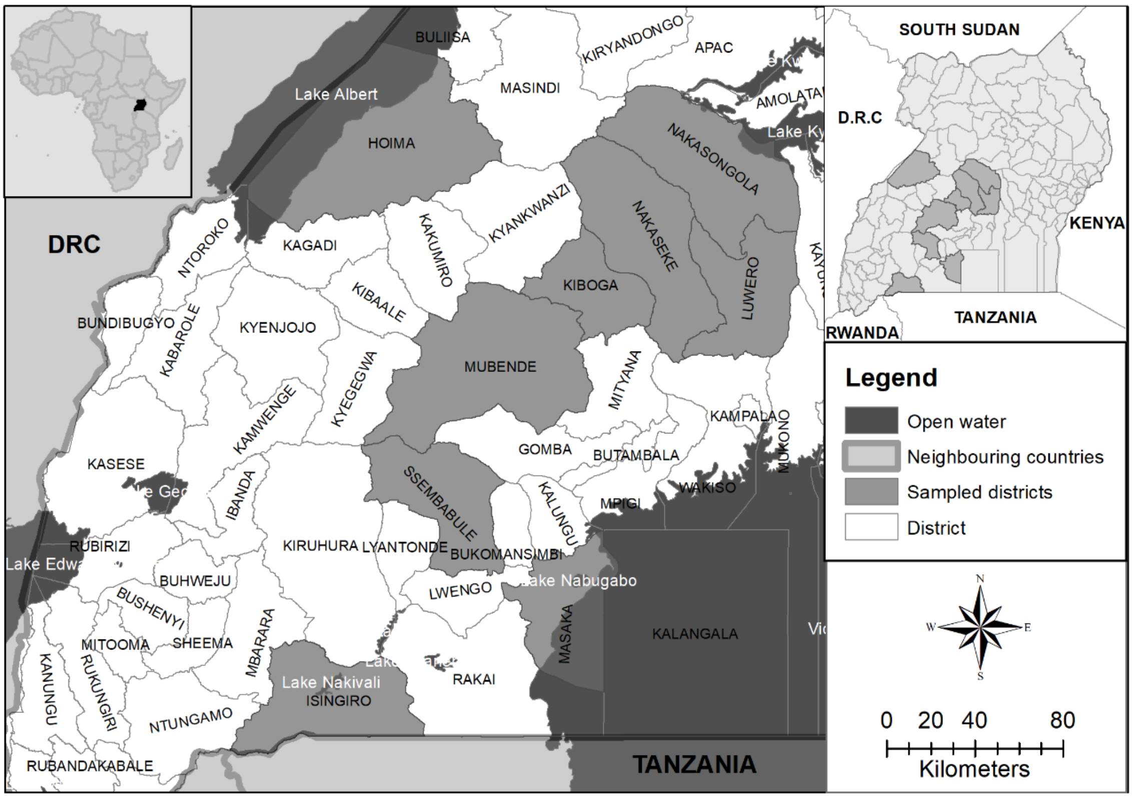


Figure 1. Location of the study area

Table 1. Description of rainwater harvesting technologies used in Uganda

RWH technology types	Description of technology
Jars	Water jars are relatively small capacity harvesting and storage vessels shaped like pots or bottles with volumes usually ranging from less than 100 litres to 2000 litres. The sizes commonly used in Uganda range from about 300 to 2000 litres. They are made from different materials including metal sheets, earthenware, and ferrocement. The common types used in Uganda are made from ferrocement but with much lighter wire reinforcement.
Plastic tanks	Plastic tanks are factory-made and are mainly used for storage. Tanks are produced in various capacities ranging from 100 litres to 24000 litres. The larger tanks, suitable for rainwater harvesting are usually cylindrical. Plastic tanks are lightweight and easy to transport, install, and maintain.
Metallic tanks	Metallic tanks are widely used in Uganda. They are fabricated using galvanized or pre-painted corrugated iron sheets manufactured locally or imported. Depending on the materials used, the tanks can be affected by rusting which creates weaknesses and eventually leaks. Capacities range from 1000 to 15000 litres. They are easy to install and maintain. Initial corrosion when used normally creates a thin adherent film that coats the interior surface of the tank and provides protection against further corrosion.
Clay Pots	Clay pots have been used for millennia in Uganda as a part of the traditional RWH practice. While they have been largely phased out in favour of more durable plastic products, there are rural areas where knowledge and use of clay pots of various storage capacities have been preserved.

'Jerrycans' (plastic containers in range of 20-50 Litres)	Used to collect and store rainwater from underneath edges of house roofs. They are also used to transport water from other water sources. The storage capacity is certainly low.
Valley tanks	These are constructed by the excavation of soil to create a large storage pit or chamber in the ground. After the soil excavation, the sides and base of the pit are usually lined and compacted with clay to reduce the seepage of water. When it rains, surface runoff collects into the chamber for storage.
Valley dams	These are formed essentially by the construction of an earth dam across a valley by joining points along the same contour line or altitude above sea level, thereby impounding the surface runoff and creating a large storage reservoir.
Ponds	Runoff collected from hill slopes, natural watercourses, footpaths or animal tracks is stored in pits of various sizes. Most of the stored water is lost due to seepage and evaporation.
Concrete Ferrocement tanks	Ferrocement is essentially an extension of conventional reinforced cement concrete technology. It is a thin-walled construction consisting of rich cement mortar with uniformly distributed and closely spaced layers of continuous and relatively small diameter mesh (metallic or other suitable material). Compared to other cement concrete structures, those made of ferrocement are lightweight, tough, durable, crack-resistant and can be made into virtually any shape. It is a low-cost and easy-to-repair technology.
Metallic Drums	Common re-use of the standard oil drum, once empty, is used for RWH and storage. It is not uncommon to see even the smallest house erect just a meter of guttering directed into a re-used oil drum. These drums could be categorized as 'traditional' since they seem to have been used in Uganda longer than the other manufactured products.

Source: Adapted from Uganda Ministry of Water and Environment, MWE, 2015

Sampling and data collection. This study is based on a cross-sectional household survey involving a mixture of stratified random and purposive sampling. Sampling considered only smallholder farmer households that were using RWH technologies. The representative sample of the households was determined using a selection procedure by Krejcie and Morgan (1970). Accordingly, 480 respondent households were randomly and proportionally (based on population size) selected from the purposively selected districts. Stratified random sampling was used to select parish and village locations of respondent households. A semi-structured questionnaire, mainly comprised of predetermined response options, was used and directly administered to the heads of the selected households between July and September 2018. In a few cases, the questionnaire was administered to the most senior and knowledgeable of the adults available at a selected homestead. The themes of the used questionnaire included types of technologies used, household socio-economic characteristics, technology utilisation at different stages of RWH (catchment, conveyance, abstraction and maintenance), factors for use of technologies and constraints.

In addition to household-level data collection, key informant interviews and focus group discussions were held. The key informant interviews were conducted at the district level. Interviewees included officials from natural resources, agricultural production, water, planning, administration departments, and political and opinion leaders. Seven key informants were interviewed in each district. Eight focus group discussions comprising 10-12 equal numbers of males and females including youth farmers were also conducted.

Data analysis. The data collected were subjected to descriptive and inferential statistics. Descriptive statistics were used for aggregation into frequencies and summaries. A signed rank-sum test was used to analyse the characteristics and stages of utilised technologies. A binary logistic regression model was performed to examine the factors that influenced the adoption of rainwater harvesting technologies. The model was run in Statisgraphics software. The model took one of the two possible values: the factors (x-independent variables) influencing the use by the households; and the results (y-dependent variables) measured. Before running the model, multicollinearity and Chi-Square tests were performed to select appropriate independent variables. There was no multicollinearity.

The dependent variable was assigned a score of 1 'when a respondent adopted and used RWH' and a score of 0 'for no use'.
The equation of the fitted model is:

RWH = exp(eta)/(1+exp(eta))………… (Eq. 1)

Where:
eta = -98.978 - 0.873905*Age of household - 0.0153945*Altitude + 24.6163*Household size + 50.7766*Number of iron sheet roofed structures + 29.552*Grass thatched + 119.515*Iron sheets +33.7489*Clay tiles -11.99*Crop production + 18.4978*Livestock production + 0.919586*Household owned land size - 7.64797* Land tenure system - 2.39262*Sources of water (rain) - 43.4369*Education=Masters -33.5988*Education=Certificate +19.34*Education=Degree-34.4419*Education=Diploma+ 42.158*Education=Never went to school +10.6656*Education=Primaryschool-9.89449*Gender

Table 2. Independent variables used in the study

Variables	Description	Category
Respondent Factors		
Age of household head	Age (years)	Continuous
Household location altitude	Elevation (slope)	Continuous
Household size	Number of household members	Continuous
Number of Iron sheets of roofed structures	Number of iron sheets used on building used to harvest water	Continuous
Household land size	Size of land owned by a farmer	Continuous
Land tenure system	1=customary, 2=leasehold, 3= Mailoland, 4= Freeland, 5=Public land,	Categorical
Sources of water	1=Harvests rainwater, 2= Does not harvest rainwater	Categorical
Gender	1=Male, 2=Female	Categorical
Type of residential dwelling by roof material		
Grass thatched	1=Grass thatched, 2=Not thatched	Categorical
Iron sheets	1=Iron roofed, 2= Not iron roofed	Categorical
Clay tiles	1=Clay roofed, 2= Not clay roofed	Categorical
Main source livelihood		
Crop production	1=Crop is the main source of income, 2= Crop is not the main source of income	Categorical
Livestock production	1=Livestock is the main source of income, 2= Livestock is not the main source of income	Categorical
Education levels		
Education=Masters	1=Attained master's degree, 2=Not attained a master's degree	Categorical
Education=Certificate	1=Attained certificate, 2=Not attained certificate	Categorical
Education=Degree	1=Attained undergraduate degree,	

	2=Not attained an undergraduate degree	Categorical
Education=Diploma	1=Attained diploma, 2=Not diploma	Categorical
Education=Never went to school	1=Attained formal education, 2=Not attained formal education	Categorical
Education=Primary school	1=Attained primary education, 2=Not attained primary education	Categorical

RESULTS

Socio-economic characteristics of smallholder farmers. The socio-economic characteristics of smallholder farmers using RWH technologies are presented in Table 3. The results of this study show that the harvested rainwater is majorly used for domestic purposes, livestock and crop production. The farmers using RWH technologies indicated that freehold[2] and mailo[3] tenure systems were the main forms of land ownership. On average, each household owned about 1-5 acres of land. Most of the RWH technologies were implemented within the homestead's vicinity (0-1km).

Table 3. Household socio-economic characteristics of farmers (N= 480, %)

Category	Characteristics		%
Gender	Females		60
	Males		40
Main use and type of RWH system	Domestic (RWH water jars, plastic tanks, metallic tanks, clay pots, Jerrycans, concrete ferro tanks)		50
	Livestock production (metallic tanks, plastic tanks, valley tanks, valley dams, ponds)		30
	Crop production (valley tanks, valley dams, ponds,)		20
Overall average size of land owned	1-5 acres		
Land tenure	Freehold		48
	Mailo		26
	Leasehold[5]		12
	Public		8
	Customary land		6
Average distance to RWH facility	Residential RWH systems	0-1Km	70
	Non-residential	1-4km	30
Source of information on RWH	Indigenous knowledge and experience		60
	Agricultural extension		12
	Neighbours and friends		11
	Local leaders		9
	Radio/Television		6
	Internet and social media		2

[2]Individualized type of land tenure.
[3]Mailo land tenure is a landlord-tenant tenure system unique to Uganda introduced in the colonial era (Van Leeuwen, 2014). The tenure guarantees the secu rity of occupancy of tenants and other lawful occupants, who have used or developed land un challenged by the owner for at least 12 years (Munk et al., 2013).
[4]Leasehold tenure system provides for access to land through a time-bound contract (Munk et al., 2013).

RWH technologies adopted by the farmers. The RWH technologies used by farmers can be broadly characterised as residential and non-residential (Table 4). Results of the signed-rank sum test show that Jerrycans, metallic drums, metallic tanks, plastic tanks, concrete ferrocement tanks, and ponds are relatively the most important residential RWH technologies. The rainwater harvesting jars are the least used by smallholder farmers. During the focus group discussions and informant interviews, participants indicated that the majority of the technologies are individually (household) owned.

Characterisation of rainwater harvesting technologies. At catchment level, roof surfaces (iron sheets, grass) and vegetation cover were the most important modes of collecting rainwater. The various catchment modes, conveyance and abstraction methods and materials for the different RWH technologies are presented in Table 5. Water is predominantly conveyed for collection and/or storage using gutters and pipes. At the abstraction stage, the most used means were: metallic taps on concrete ferrocement tanks, electric pumping systems to light-handled withdrawal containers such as cups, and jars especially where metallic drums are used.

Maintenance practices of rainwater harvesting technologies. The most predominant maintenance practices employed to clean technologies (Jerrycans, metallic drums, metallic tanks, plastic tanks, concrete ferrocement tanks, ponds) by smallholder farmers include cleaning, desilting and fencing (Figure 2).

Table 4. Utilisation of existing rainwater harvesting technologies (N=480)

District	Jars	Plastic tanks	Metallic tanks	Clay pots	Jerrycans	Valley tanks	Valley dams	Ponds	Concrete ferro cement tanks	Metallic drums
Hoima	0	2	2	1	36	2	0	2	14	32
Isingiro	0	10	2	1	43	3	1	6	36	8
Kiboga	5	31	7	0	17	9	12	3	3	12
Luweero	0	3	4	5	4	7	7	1	13	29
Masaka	0	0	0	0	1	0	0	0	0	1
Mubende	0	4	4	0	8	0	1	1	3	27
Nakaseke	0	8	2	0	10	1	1	5	10	43
Nakasongola	0	7	1	3	13	14	20	2	1	38
Sembabule	1	5	3	2	44	36	5	33	3	43
Signed rank sum test										
P-value	0.57	0.0076*	0.0070*	0.06	0.003*	0.0155*	0.015*	0.009*	0.0078*	0.0039*

[5]Typically small volume systems (200-400 m3) that capture rooftop runoff, generally for domestic consumption purposes (Kiggundu et al. 2018).

Table 5. Characterisation of rainwater harvesting technologies at various stages (N=480, n (%); Mean)

Stage of RWH	Plastic tanks	Metallic tanks	Jerry cans	Valley tanks	Valley dams	Ponds	Concrete ferrocement tanks	Metallic drums	P-Value
Catchment									
Roof surface	62(13.5)	24(5.2)	180(39.1)	14(30)	0(0)	3(0.7)	86(18.7)	240(52.2)	0.02*
Vegetation	1(0.2)	0(0)	1(0.2)	31(6.8)	5(1.1)	14(3)	0(0)	1(0.2)	0.04*
Bare soil	0(0)	0(0)	0(0)	26(5.7)	30(6.5)	15(3.3)	0(0)	0(0)	0.74
Impervious structures	0(0)	0(0)	0(0)	1(0.2)	2(0.4)	1(0.2)	0(0)	0(0)	0.72
Conveyance method									
Gutters	63(13.7)	42(9.1)	141(30.7)	12(2.6)	1(0.2)	2(0.4)	90(19.6)	251(54.6)	0.001*
Pipes	14(3)	8(1.7)	3(0.7)	2(0.4)	0(0)	0(0)	18(3.9)	3(0.7)	0.04*
Sticks/reeds	0(0)	0(0)	42(9.1)	0(0)	1(0.2)	0(0)	1(0.2)	14(3)	0.31
Bare canals	0(0)	0(0)	0(0)	38(8.2)	32(7)	22(4.8)	0(0)	3(0.7)	0.33
Vegetated canals	0(0)	0(0)	0(0)	25(5.4)	5(1.1)	10(2.2)	0(0)	0(0)	0.74
Galvanized iron sheets	0(0)	0(0)	4(0.9)	1(0.2)	0(0)	0(0)	1(0.2)	1(0.2)	0.31
Conveyance material									
PVC pipe	22(4.8)	17(3.7)	10(2.2)	6(1.3)	0(0)	0(0)	30(6.5)	20(4.3)	0.039*
Galvanized steel sheet	7(1.5)	7(1.5)	14(3)	2(0.4)	0(0)	1(0.2)	21(4.5)	55(11.7)	0.015*

Roofing sheet	46(10)	21(4.6)	109(23.7)	8(1.7)	0(0)	3(0.7)	38(8.3)	170(37)	0.01*
wood/plant system	0(0)	1(0.2)	38(8.3)	0(0)	0(0)	0(0)	1(0.2)	12(2.6)	0.30
Vegetation	0(0)	0(0)	1(0.2)	39(8.5)	38(8.2)	25(5.4)	1(0.2)	3(0.7)	0.04*
Abstraction method									
Taps	58(12.6)	45(9.8)	1(0.2)	1(0.2)	0(0)	0(0)	82(17.8)	3(0.7)	0.04*
jars/cups	18(3.9)	5(1.1)	84(18.3)	67(14.6)	27(5.9)	33(7.2)	25(5.4)	272(59.1)	0.01*
Pumping systems	1(0.2)	0(0)	5(1.1)	10(2.2)	14(3)	1(0.2)	2(0.4)	3(0.7)	0.012*

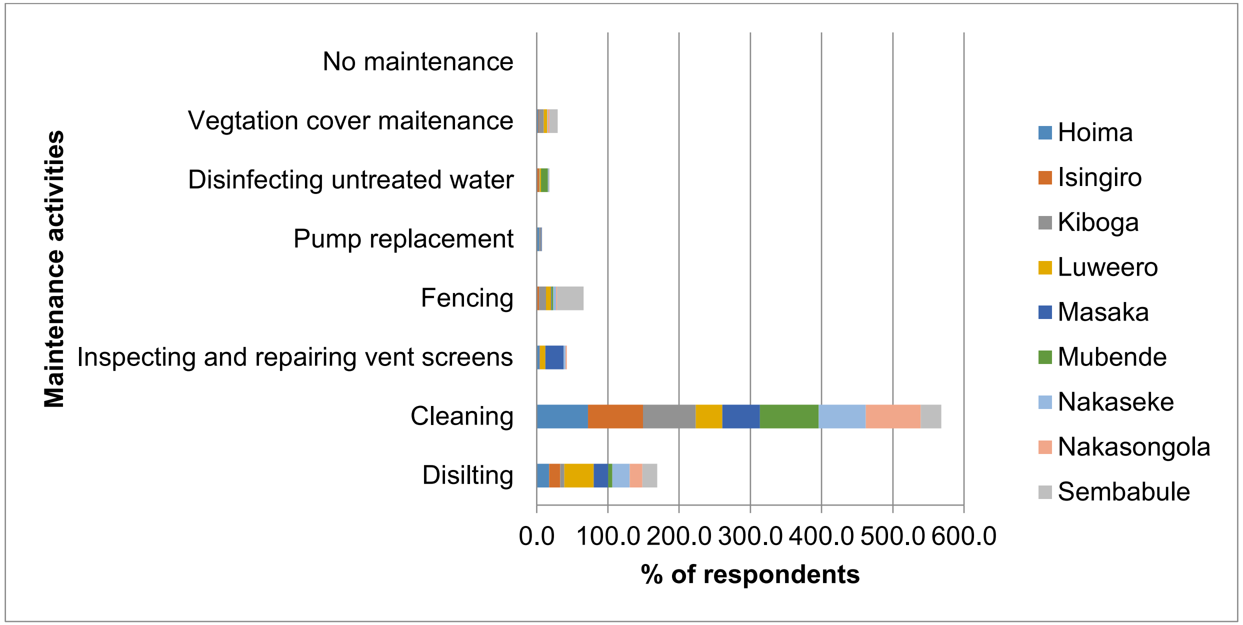


Figure 2. Maintenance practices undertaken in rainwater harvesting technologies (Jerrycans, metallic drums, metallic tanks, plastic tanks, concrete ferrocement tanks, ponds)

[6]Polyvinyl chloride (PVC) is a solid plastic made from vinyl chloride.

Most of the farmers indicated that they were not covering their RWH facilities unless the technology had been designed or fitted with the original cover to protect the water from contamination (Figure 3). A few of the farmers indicated to have used small pieces of iron sheets, saucepans and planting of cover grass to protect water facilities. Pieces of iron sheets used to protect water were commonly observed during field visits, especially in the districts of Luweero and Masaka.

Determinants for the adoption of rainwater harvesting technologies by the smallholder farmers. The age of a farmer, household membership size, and engagement in livestock production were the most important determinants of the use of RWH technologies (Tables 6 and 7). The coefficient of the age of the farmer was negatively associated with the use of RWH technologies, which means a low likelihood of use by older farmers. Households with bigger family sizes were more likely to adopt and use RWH technologies, in comparison with the households with smaller membership sizes. With a unit increase in the number of family members (an additional member), the results show that such farmers were (odds ratio=4.9) more likely to adopt and use RWH technologies. Ownership of more iron sheets roof surface positively influenced the use of RWH technologies. An increase in the number of house units in any homestead was more likely to lead to the use of RWH technologies (odds ratio=1.2).

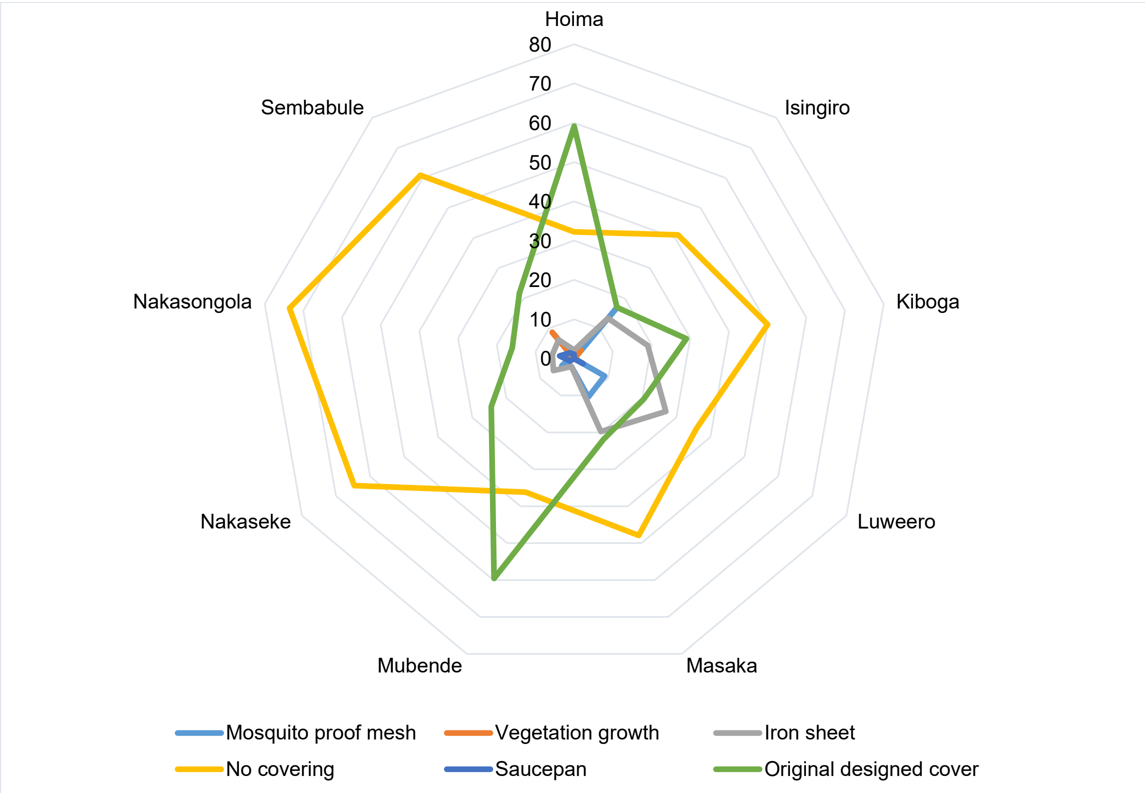


Figure 3. Characteristics of water source protection practices

Table 6. Estimated regression model (maximum likelihood) for factors that influenced the adoption of rainwater harvesting technologies (n= 480)

Parameter	Estimate	Standard Error	Estimated Odds Ratio
CONSTANT		-98.978	330.385
Household Factors			
Age of household	-0.873905	0.317837	0.417319
Household location altitude	-0.0153945	0.0375725	0.984723
Household size	24.6163	8.96957	4.90604E10
Number of iron sheet roofed structures	50.7766	13.3988	1.12717E22
Household land size	0.919586	9.43671	2.50825
Land tenure system	-7.64797	4.22453	0.000477011
Sources of water (rain)	-2.39262	6.45703	0.0913897
Gender	-9.89449	23.631	0.0000504519
Type of roof material of residential dwelling			
Grass	29.552	30.143	6.82749E12
Iron sheets	119.515	318.339	8.03101E51
Clay tiles	33.7489	50.8107	4.53922E14
Main source livelihood			
Crop production	-11.99	72.2631	0.000006206
Livestock production	18.4978	18.4535	1.08022E8
Education levels			
Education=Masters	-43.4369	317.613	1.3664E-19
Education=Certificate	-33.5988	66.0606	2.55993E-15
Education=Degree	19.34	82.0964	2.5076E8
Education=Diploma	-34.4419	56.7827	1.10168E-15
Education=Never went to school	42.158	29.9826	2.03688E18
Education=Primary school	10.6656	9.13549	42857.1

Table 7. Determinants for the adoption of RWH technologies by the smallholder farmers

Factors	Chi-Square	Df	P-Value
Age of a farmer	4.30298	1	0.0380*
Altitude/elevation	0.0192141	1	0.8898
Household membership size	8.8355	1	0.0030*
Number of iron sheet roofed structures	11.4543	1	0.0007
Grass thatched	1.11373	1	0.2913
Use of iron sheets	0.00102102	1	0.9745
Clay tiles	1.41653	1	0.2340
Involvement in crop production	-0.00102791	1	1.0000
Involvement in livestock production	5.66925	1	0.0173*
Household land size	0.00374038	1	0.9512
Land tenure system	0.187714	1	0.6648
Sources of water (rain)	0.0119388	1	0.9130
Education level	7.76484	6	0.2558
Gender	0.0834805	1	0.7727

Limitations to the adoption and utilization of rainwater harvesting technologies. The farmers indicated the major limitations of adopting and using RWH technologies to be the small capacity of available systems, contamination of water sources by people and animals, leaks, seepage, and siltation (Figure 4). The limited capacity of the utilized residential and non-residential RWH systems was a shared constraint across all the districts. The key informant interviews showed that for plastic tanks, the constraints include vandalism and limited financial resources to purchase them. Focus group discussions information showed that the use of pots is limited by damage and breakage caused by children, contamination from animals (rats fall and die in the water), and mosquito breeding. For the concrete ferrocement tanks, usage is limited by seepage, frequent breakage of taps, short durability, and shortage of some construction materials. The use of metallic drums was associated with accidents of children drowning, contamination, limited storage capacity, and theft. It was noticed from focus group discussions that the use of valley tanks is limited by the associated high labour expenses needed to establish them.

DISCUSSION

In the study area, most (74%) of the farmers who were using RWH technologies owned land under freehold and mailo tenure. These land tenure systems enable the permanent establishment of some of the RWH technologies (especially dams) among the farmers (Aberra, 2004; Mucheru-Muna *et al*., 2017). The tenure systems legitimately give absolute rights to own and use RWH technologies (Bouma *et al*., 2012; Nyamadzawo *et al*., 2013). The security of land tenure, therefore, appears to be increasing the likelihood of farmers to invest in RWH assets for responding to drought effects and risks, hence an improvement of livelihood stands. Studies in Bangladesh and South Africa have shown that more secure tenure rights among farmers were more likely to positively influence their adaptation to water scarcity through RWH (Alam, 2015; Baiyegunhi, 2015). In addition, a review of trends and constraints of smallholder irrigation in East Africa highlights land tenure rights as a factor for adopting RWH among

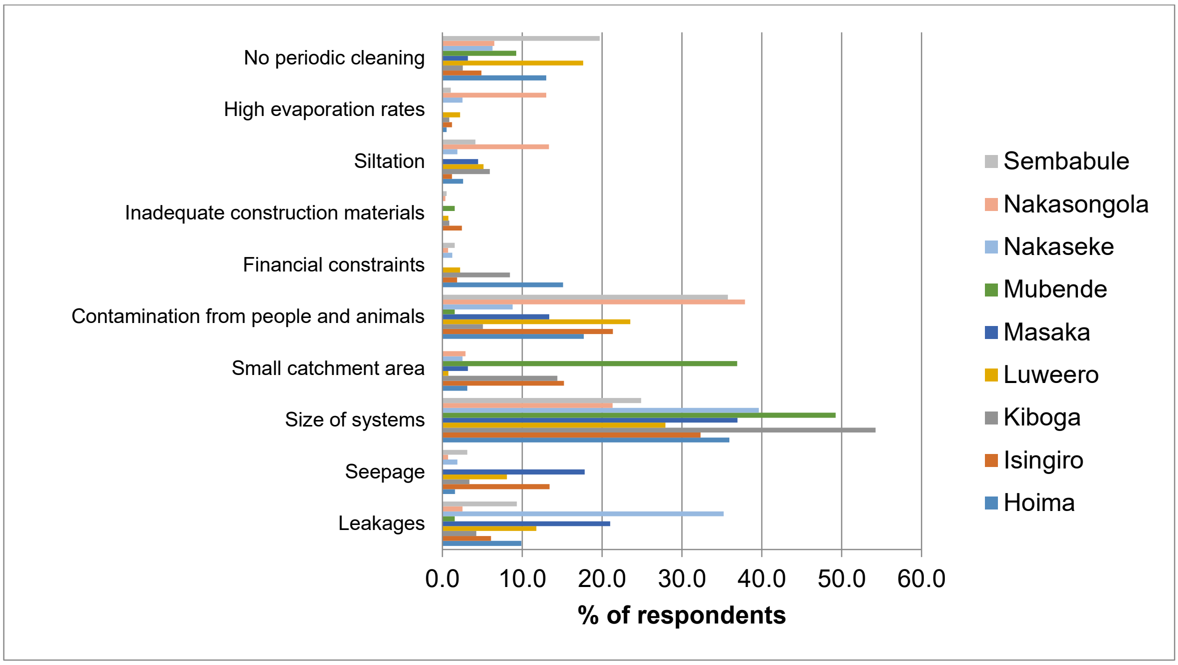


Figure 4. Limitations to the use of rainwater harvesting technologies

smallholder farmers (Nakawuka *et al.,* 2018).

On the other hand, having the smallest proportions of farmers under customary land using RWH technologies points to the likelihood that this tenure system could be limiting the level of use. Since the customary land tenure system is under traditional or cultural institutions, smallholder farmers who are squatters on such land are likely to feel insecure to invest in RWH systems. This is plausibly due to a lack of guarantee that such investments would translate into permanent use and benefits for their livelihood capacity and activities (Goldstein and Udry, 2008). Related studies have shown that the location of water sources on customary owned land presents threats of disputes over access and related payments for using the land between the users and traditional owners of the land (Quigley *et al.,* 2016).

In the study area, roof surfaces (iron sheets, grass) and vegetation cover were the most important modes of collecting rainwater. This could be attributed to the small sizes of land (between 1-5 acres) that constrain farmers' RWH catchment options. This result is related to other studies showing that small size land ownership in Sub-Saharan Africa is a key drawback to the implementation of both residential and non-residential RWH systems for domestic use and agricultural production (e.g. Drechsel *et al.,* 2005; Gurung and Sharma, 2014). It is apparent that amidst the land limitations, the capacity of the current RWH technology systems used was not likely to sustain domestic, livestock, and crop production water demands for drought response. Focus group discussions showed that there is overlapping demand for water that at times creates trade-offs in its use in relation to livelihood activities. In this case, most of the farmers were using residential RWH technologies, hence the reason most of the water was mainly limited to serving household consumption purposes (Kiggundu *et al.,* 2018). A related study in the semi-arid region of Kenya similarly reported that most of the harvested rainwater was mainly used for domestic needs (Kalungu *et al.,* 2015).

Roof surface, gutters and taps were the most utilized RWH technologies for catchment, conveyance and abstraction respectively. This is not surprising because most of the systems for RWH are residential, requiring the use of these options over others at the household level. The prevalence of these is also most likely due to the low costs of the materials for the technologies that are within the incomes of the farmers. Regarding the conveyance stage, Polyvinyl chloride (PVC) pipes came out as the most used material to channel water from rooftops to the collection devices. A study by Kimani *et al.* (2015) in Kenya, also reported the predominant use of similar materials and devices for rooftop-based RWH technologies.

Most farmers depend on indigenous and experiential knowledge of drought and rainwater management as the main basis for using RWH technologies. Only 12% of the respondents were using knowledge from professional extension services. This is possible because of the long history of some of the RWH techniques used and passed on to different generations (Mercer *et al.,* 2010; Orlove *et al.,* 2010; Raymond *et al.,* 2010). On the other hand, it could be due to the low level of agro-advisories and limited availability of information tailored to the use of RWH technologies for drought management as was established during focus group discussions. As was indicated by Caswell *et al.* (2001), farmers will only adopt and use the technology they are aware of or have heard about. Access to information reduces the uncertainty about a technology's performance hence may change an individual's assessment from purely subjective to objective over time (Bonabana-Wabbi, 2002). Therefore, limited use of scientific information and lack of technical know-how about potentially better RWH technologies amongst smallholder farmers restricts the level of use of modern and possibly more capacity and efficient RWH technologies.

The dependency on indigenous knowledge by the farmers shows that it is still relevant and avails avenues for integration with scientific information while dealing with the present-day water-stressed conditions. Bhattacharya (2015) indicated that traditional water harvesting wisdom in India (including the use of bamboo pipes, and runoff impoundment ponds, among others) at all levels of society had enabled adequate availability of water for all, which in turn formed a basis for all-round development and prosperity. Other studies have also shown that traditions continue to serve as a basis for coping with drought, water stress and storm events. For example, in Nepal, traditional RWH for supplemental domestic and agriculture has been uninterrupted for nearly 15 centuries (Ghimire and Johnston, 2015).

The significant socio-economic determinants of RWH technology use in the study area are engagement in livestock production, age of a farmer and household membership size. Farmers whose livelihoods predominantly depend on livestock invest more in RWH technologies to meet the high and continuous demand for water by livestock, particularly during dry spells and droughts. Other studies (e.g., Vermeulen and Wynter, 2014) have also shown that livestock-dependent farmers are more likely to uptake information and technologies to adapt to changing conditions. The results also show that younger farmers are more likely to use RWH technologies than their older counterparts. The lower likelihood of older farmers adopting agriculture-related technologies has been attributed to their high level of risk aversion. Age is sometimes believed to increase risk aversion and decreased interest in long-term investment in farming. On the contrary, youthful farmers are less risk-averse and are more likely to venture into new technologies (Mauceri *et al.,* 2005; Mwangi and Kariuki 2015).

Households with bigger membership sizes were more likely to use RWH harvesting technologies than those with a smaller number of people. This could be related to the fact that most of the household labour, in the study area, is mainly provided by family members including activities such as establishing and maintaining RWH technologies. Therefore, household size can be looked at as a measure of labour availability and livelihood capacity for supporting the establishment of RWH systems and other drought response options. Studies have shown that household size determines the adoption process in that, a larger household can relax the labour constraints required especially during the introduction of new technology (Bonabana- Wabbi, 2002; Mignouna *et al.,* 2011).

The low capacity across all RWH systems was perceived by farmers as the principal setback to the optimal utilization of RWH. Small residential RWH systems were predominantly used leading to harvesting quantities of water that are far less than the water demands during dry spells and droughts. Looking at the socio-economic characteristic of the farmers, this could be due to a lack of affordability. Studies have shown low levels of income to be the most likely reason why most farmers are not able to establish higher capacity RWH systems (Biazin *et al.,* 2012; Jafari *et al.,* 2016). Domènech *et al* (2012) highlight that the inability of vulnerable households to invest in and maintain RWH technologies poses a risk to insufficient quantity of harvested and available water for use when needed.

CONCLUSIONS

In this paper, we have characterised the RWH technologies used by smallholder farmers in drought-prone areas of Uganda. The paper also analyses the determinants of the use of RWH technologies and sheds light on the limitations for optimal use of RWH technologies. RWH technologies, among farmers, in the study area, are characterised by the use for domestic purposes with limited use for agricultural production; small volume systems that capture rooftop runoff without further treatment; predominant use of indigenous and experiential knowledge, and use of basic catchment, conveyance, abstraction and storage techniques. Fewer farmers owning customary land (tenure system where clan and other chiefs exercise control over land) are using RWH technologies compared to those owning land on mailo (an individualized type of land tenure system in Uganda) and freehold tenure. The pattern of use is significantly influenced by the level of livelihood dependence on livestock, age of a farmer and household size. The optimal use of RWH by the farmers is limited by capacity and water quality maintenance constraints. The major constraint is the low quantity capacity of the technologies in place. Leaks, seepage, siltation and contamination are common issues associated with most of the water harvesting techniques used by farmers. Shortage of water dictates trade-offs that limit farmers to domestic use of harvested water and not for agricultural production.

The existing and predominant use of indigenous and experiential knowledge provides an opportunity that can be leveraged through integration with scientific information while dealing with the current water constraints in response to dry spells and drought. Knowledge and technical support systems to improve RWH should prioritise increasing harvesting capacity to extend the use beyond domestic use to crop and livestock production. The capacity improvements will need to take into consideration of water quality management limitations to deal with the current resource demands for cleaning, desilting and fencing of harvested water from land use and other sources of contamination. This will require technical capacity building including awareness-raising and training on both micro and macro rainwater harvesting systems management. The higher potential of interest in and use of the technologies by the younger farmers needs to be explored to catalyse improvements in the quantity of harvested water. A pilot strategy on appropriate size tanks to facilitate RWH in the area needs to be developed and investigated for community acceptance and use. In so doing, it is essential to develop policies and other mechanisms that can facilitate the establishment of RHW technologies in ways that will guarantee the security of ownership and use of land and technology systems and associated assets. This way, more farmers owning or using land on customary and leasehold tenure might be able to undertake more investments and use the technologies. This will most likely lead to livelihood diversification through, for example, more crop farmers adopting livestock farming due to increased availability and access to the required water.

ACKNOWLEDGEMENT

This study was financially supported by USAID and implemented through FHI 360 and Makerere University Centre for Climate Change Research and Innovations (MUCCRI). We thank the team of dedicated research assistants who collected data in the nine study districts. Great thanks also go to the local government officials who guided the selection of studied sub-counties in the districts.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Aberra, Y. 2004. Problems of the solution: Intervention into small-scale irrigation for drought proofing in the Mekele Plateau of northern Ethiopia. *Geographical Journal* 170(3): 226–237.

AGRA. 2017. Africa Agriculture Status Report: The Business of Smallholder Agriculture in Sub-Saharan Africa (No. 5). Alliance for a Green Revolution in Africa (AGRA). https://agra.org/wp-content/uploads/2017/09/Final-AASR-2017-Aug-28.pdf

Alam, K. 2015. Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi district, Bangladesh. *Agricultural Water Management* 148: 196–206.

Antwi-Agyei, P., Dougill, A. J. and Stringer, L. C. 2015. Impacts of land tenure arrangements on the adaptive capacity of marginalized groups: The case of Ghana's Ejura Sekyedumase and Bongo districts. *Land Use Policy* 49: 203–212.

Assefa, S., Biazin, B., Muluneh, A., Yimer, F. and Haileslassie, A. 2016. Rainwater harvesting for supplemental irrigation of onions in the southern dry lands of Ethiopia. *Agricultural Water Management* 178: 325-334.

Ayanlade, A., Radeny, M., Morton, J. F. and Muchaba, T. 2018. Rainfall variability and drought characteristics in two agro-climatic zones: An assessment of climate change challenges in Africa. *Science of the Total Environment* 630: 728-737.

Baiyegunhi, L. J. S. 2015. Determinants of rainwater harvesting technology (RWHT) adoption for home gardening in Msinga, KwaZulu-Natal, South Africa. *Water SA* 41(1): 33-40.

Bandiera, O. and Rasul, I. 2006. Social networks and technology adoption in Northern Mozambique. *The Economic Journal* 116 (514): 869-902.

Bhattacharya, S. 2015. Traditional water harvesting structures and sustainable water management in India: A socio-hydrological review. *International Letters of Natural Sciences* 37: 30-38.

Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A. and Stroosnijder, L. 2012. Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa–a review. *Physics and Chemistry of the Earth, Parts A/B/C* 47: 139–151.

Bonabana-Wabbi, J. 2002. Assessing factors affecting adoption of agricultural technologies: The case of Integrated Pest Management (IPM) in Kumi District, Eastern Uganda. Doctoral dissertation, Virginia Tech.

Bouma, J., Critchley, W. and Barron, J. 2012. A review of the recent literature on water harvesting in Sub-Saharan Africa. Routledge: New York.

Brauman, K. A., Siebert, S. and Foley, J. A. 2013. Improvements in crop water productivity increase water sustainability and food security—A global analysis. *Environmental Research Letters* 8 (2): 024030. https://doi.org/10.1088/1748-9326/8/2/024030.

Caswell, M., Fuglie, K. O., Ingram, C., Jans, S. and Kascak, C. 2001. Adoption of agricultural production practices: lessons learned from the US Department of Agriculture Area Studies Project (No. 1473-2016-120785).

Chivenge, P., Mabhaudhi, T., Modi, A. T. and Mafongoya, P. 2015. The potential role of neglected and underutilised crop species as future crops under water scarce conditions in sub-Saharan Africa. *International Journal of Environmental Research and Public Health* 12(6): 5685–5711. https://doi.org/10.3390/ijerph120605685.

Critchley, W. and Gowing, J. W. (Eds.). 2012. Water Harvesting in Sub-Saharan Africa. Routledge.

Domènech, L., Heijnen, H. and Saurí, D. 2012. Rainwater harvesting for human consumption and livelihood improvement in rural N epal: Benefits and risks. *Water and Environment Journal* 26(4): 465–472.

Drechsel, P., Olaleye, A., Adeoti, A., Thiombiano, L., Barry, B. and Vohland, K. 2005. Adoption driver and constraints of resource conservation technologies in sub-Saharan Africa. Berlin: FAO, IWMI, Humbold Universitaet 1–21pp.

Dube, T., Moyo, P., Ncube, M. and Nyathi, D. 2016. The impact of climate change on agro-ecological based livelihoods in Africa: A review. J*ournal of Sustainable Development* 9 (1): 256–267.

DWRM. 2011. National water resources assessment draft report. Directorate of Water Resources Management, Ministry of Water and Environment- Government of Uganda.

Eakin, H. C., Lemos, M. C. and Nelson, D. R. 2014. Differentiating capacities as a means to sustainable climate change adaptation. *Global Environmental Change* 27: 1–8.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K. and West, P. C. 2011. Solutions for a cultivated planet. *Nature* 478 (7369): 337-342.

Ghimire, S. R. and Johnston, J. M. 2015. Traditional knowledge of rainwater harvesting compared to five modern case studies. 182–193 pp. In: World Environmental and Water Resources Congress 2015: Floods, Droughts, and Ecosystems.

Giordano, M., Namara, R. and Bassini, E. 2019. The impacts of irrigation: A review of published evidence. The World Bank 46pp.

Goldstein, M. and Udry, C. 2008. The Profits of Power: Land Rights and Agricultural Investment in Ghana. *Journal of Political Economy* 116 (6): 981–1022. https://doi.org/10.1086/595561

Graeub, B. E., Chappell, M. J., Wittman, H., Ledermann, S., Kerr, R. B. and Gemmill-Herren, B. 2016. The State of Family Farms in the World. *World Development* 87: 1–15. https://doi.org/10.1016/j.worlddev.2015.05.012

Hall, B. F. and LeVeen, E. P. 1978. Farm size and economic efficiency: The case of California. *American Journal of Agricultural Economics* 60 (4): 589–600.

Harris, D. and Orr, A. 2014. Is rainfed agriculture really a pathway from poverty? *Agricultural Systems* 123: 84–96. https://doi.org/10.1016/j.agsy.2013.09.005

Harvey, C. A., Rakotobe, Z. L., Rao, N. S., Dave, R., Razafimahatratra, H., Rabarijohn, R. H., Rajaofara, H. and MacKinnon, J. L. 2014. Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of the Royal Society B: Biological Sciences* 369(1639): 20130089.

Jafari Shalamzari, M., Sheikh, V. B., Saadodin, A. and Abedi Sarvestani, A. 2016. Public Perception and acceptability toward domestic rainwater harvesting in Golestan, limits to up-scaling. *Ecopersia* 4(3): 1437–1454.

Kakeeto, R., Sibiya, J., Melis, R. and Biruma, M. 2019. Farmers' perceptions of drought and other production constraints, drought mitigation options and their implications for groundnut breeding in Uganda. *Indian Journal of Agricultural Research* 53(1): 45-50.

Kalungu, J. W., Filho, W. L., Mbuge, D. O. and Cheruiyot, H. K. 2015. Assessing the impact of rainwater harvesting technology as adaptation strategy for rural communities in Makueni County, Kenya. Handbook of Climate Change Adaptation, 1615–1634.

Kharraz, J. E., El-Sadek, A., Ghaffour, N. and Mino, E. 2012. Water scarcity and drought in WANA countries. *Procedia Engineering* 33: 14–29. https://doi.org/10.1016/j.proeng.2012.01.1172

Kiggundu, N., Wanyama, J., Mfitumukiz, D., Twinomuhangi, R., Barasa, B., Katimbo, A. and Kyazze, F. 2018. Rainwater harvesting knowledge and practice for agricultural production in a changing climate: A review from Uganda's perspective. *Agricultural Engineering International: CIGR Journal* 20 (2): 19–36.

Kijne, J., Barron, J., Hoff, H., Rockström, J., Karlberg, L., Gowing, J., Wani, S. P. and Wichelns, D. 2009. Opportunities to increase water productivity in agriculture with special reference to Africa and South Asia. Stockholm Environment Institute.

Kilimani, N., van Heerden, J. and Bohlmann, H. 2016. Water resource accounting for Uganda: Use and policy relevancy. *Water Policy* 18 (1): 161–181.

Kimera, F. 2018. Economic benefits of surface runoff harvesting for supplemental irrigation for sub-saharan Africa: Case study of Soroti, Uganda [Masters Thesis]. The American University in Cairo.

Krejcie, R. V. and Morgan, D. W. 1970. Determining sample size for research activities. *Educational and Psychological Measurement*, 30 (3): 607–610.

Kumar, K. M., Sridhara, C. J., Hanumanthappa, M. and Marimuthu, S. 2019. A review of impacts and mitigation strategies of climate change on dryland agriculture. *Current Journal of Applied Science and Technology* 33(4): 1-12.

Kummu, M., Guillaume, J. H. A., de Moel, H., Eisner, S., Flörke, M., Porkka, M., Siebert, S., Veldkamp, T. I. E. and Ward, P. J. 2016. The world's road to water scarcity: Shortage and stress in the 20th century and pathways towards sustainability. *Scientific Reports* 6 (1):1-16. https://doi.org/10.1038/srep38495

Londra, P. A., Theocharis, A. T., Baltas, E. and Tsihrintzis, V. A. 2018. Assessment of rainwater harvesting tank size for livestock use. W*ater Science and Technology: Water Supply* 18 (2): 555–566.

Lowder, S. K., Skoet, J. and Raney, T. 2016. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development* 87:16–29. https://doi.org/10.1016/j.worlddev.2015.10.041

Mauceri, M., Alwang, J., Norton, G. and Barrera, V. 2005. Adoption of integrated pest management technologies: A case study of potato farmers in Carchi, Ecuador. In Memorias Annual Meeting American Agricultural Economics Association, Providence (RI).

Mercer, J., Kelman, I., Taranis, L. and Suchet-Pearson, S. 2010. Framework for integrating indigenous and scientific knowledge for disaster risk reduction. *Disasters* 34 (1): 214–239.

Mignouna, D. B., Manyong, V. M., Mutabazi, K. D. S. and Senkondo, E. M. 2011. Determinants of adopting imazapyr-resistant maize for Striga control in Western Kenya: A double-hurdle approach. *Journal of Development And Agricultural Economics* 3 (11): 572-580.

Moswetsi, G., Fanadzo, M. and Ncube, B. 2017. Cropping systems and agronomic management practices in smallholder farms in South Africa: Constraints, challenges and opportunities. *Journal of Agronomy* 16 (2): 51-64.

Mucheru-Muna, M., Waswa, F. and Mairura, F. S. 2017. Socio-economic factors influencing utilisation of rain water harvesting and saving technologies in Tharaka South, Eastern Kenya. *Agricultural Water Management* 194: 150–159.

Mugerwa, S., Kayiwa, S. and Egeru, A. 2014. Status of Livestock Water Sources in Karamoja Sub-Region, Uganda. *Resources and Environment* 4(1): 58–66. https://doi.org/10.5923/j.re.20140401.07.

Makuma-Massa, H., Bemigisha, J., Kyasimire, B., Nyiramahoro, E., Begumana, J., Mugerwa, S. and Cho, M. 2017. Mapping the potential for hay making in rangelands: a methodological proposition. *Rangelands* 39 (5): 152-162.

Munk Ravnborg, H., Bashaasha, B., Pedersen, R. H., Spichiger, R. and Turinawe, A. 2013. Land tenure under transition: Tenure security, land institutions and economic activity in Uganda. DIIS Working Paper.

Muyanga, M. and Jayne, T. S. 2014. Effects of rising rural population density on smallholder agriculture in Kenya. *Food Policy* 48: 98–113. https://doi.org/10.1016/j.foodpol.2014.03.001

Mwangi, M. and Kariuki, S. 2015. Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *Journal of Economics and Sustainable Development* 6 (5): 208-216.

MWE. 2015. Handbook on Rainwater Harvesting Storage Options. Ministry of Water and Environment, Uganda. https://www.mwe.go.ug/sites/default/files/library/Rain%20Water%20Harvesting%20Handbook.pdf.

Nakabugo, R., Mukwaya, I. P. and Geoffrey, S. 2019. Adoption of climate smart agricultural technologies and practices in drylands in Uganda: Evidence from a Microlevel study in Nakasongola District. 541-568pp. In: Agriculture and Ecosystem Resilience in Sub Saharan Africa. Springer, Cham.

Nakawuka, P., Langan, S., Schmitter, P. and Barron, J. 2018. A review of trends, constraints and opportunities of smallholder irrigation in East Africa. *Global Food Security* 17: 196–212. https://doi.org/10.1016/j.gfs.2017.10.003

Niang (Senegal, I., C. Ruppel (Namibia, O., Abdrabo, M., Essel (Ghana, A., Lennard, C., Padgham (USA, J., Urquhart (South Africa, P., Adelekan, I., Archibald, S., Balinga (Cameroon, M., Barkhordarian, A., Battersby, J., Bilir (USA, E., Burke (USA, M., Chahed (Tunisia, M., Chatterjee (USA/India, M., Chineke, T., Descheemaeker (Netherlands, K., Houria, D. and Leary, N. 2014. Chapter 22 Africa. 1199–1265 pp. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Barros, V. R. (Ed.).

Nimusiima, A., Basalirwa, C. P. K., Majaliwa, J. G. M., Otim-Nape, W., Okello-Onen, J., Rubaire-Akiiki, C., Konde-Lule, J. and Ogwal-Byenek, S. 2013. Nature and dynamics of climate variability in the uganda cattle corridor. *African Journal of Environmental Science and Technology* 7 (8): 770-782–782. https://doi.org/10.5897/AJEST2013.1435

Nnaji, C. C. 2019. Sustainable Water supply in buildings through rooftop rainwater harvesting. Construction Industry Development Board Postgraduate Research Conference 390–400pp.

Nsubuga, N. W. F., Namutebi, N. E. and Ssenfuma, N.-M. 2014. Water resources of Uganda: An assessment and review. *Journal of Water Resource and Protection* 6 (14): 1–18. https://doi.org/10.4236/jwarp.2014.614120

Nyamadzawo, G., Wuta, M., Nyamangara, J. and Gumbo, D. 2013. Opportunities for optimization of in-field water harvesting to cope with changing climate in semi-arid smallholder farming areas of Zimbabwe. *SpringerPlus* 2 (1):1-9.

Oremo, F., Mulwa, R. and Oguge, N. 2019. Knowledge, attitude and practice in water resources management among smallholder irrigators in the Tsavo sub-catchment, Kenya. *Resources* 8 (3): 1-17.

Orlove, B., Roncoli, C., Kabugo, M. and Majugu, A. 2010. Indigenous climate knowledge in southern Uganda: The multiple components of a dynamic regional system. *Climatic Change* 100 (2): 243–265.

Oweis, T., Hachum, A. and Kijne, J. 1999. Water harvesting and supplemental irrigation for improved water use efficiency in dry areas (Vol. 7). IWMI.

Pachpute, J. S., Tumbo, S. D., Sally, H. and Mul, M. L. 2009. Sustainability of rainwater harvesting systems in rural catchment of sub-Saharan Africa. *Water Resources Management* 23 (13): 2815–2839. https://doi.org/10.1007/s11269-009-9411-8

Quigley, N., Beavis, S. G. and White, I. 2016. Rainwater harvesting augmentation of domestic water supply in Honiara, Solomon Islands. *Australian Journal of Water Resources* 20 (1): 65–77.

Rankoana, S. 2016. Perceptions of climate change and the potential for adaptation in a rural community in Limpopo Province, South Africa. *Sustainability* 8(8): 1-10.

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M. and Evely, A. C. 2010. Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management* 91(8): 1766–1777.

Recha, C. W., Mukopi, M. N. and Otieno, J. O. 2015. Socio-economic determinants of adoption of rainwater harvesting and conservation techniques in semi-arid Tharaka Sub-County, Kenya. *Land Degradation and Development* 26 (7): 765–773.

Rockstrom, J. and Baron, J. 2003. Water harvesting to upgrade smallholder farming: Experiences from on-farm research in Kenya and Burkina Faso. RELMA, Nairobi. http://www.worldagroforestry.org/downloads/Publications/PDFS/WP15616.pdf

Rockström, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J. and Qiang, Z. 2010. Managing water in rainfed agriculture—The need for a paradigm shift. *Agricultural Water Management* 97 (4): 543–550.

Samberg, L. H., Gerber, J. S., Ramankutty, N., Herrero, M. and West, P. C. 2016. Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters* 11(12): 124010. https://doi.org/10.1088/1748-9326/11/12/124010

Taffere, G. R., Beyene, A., Vuai, S. A., Gasana, J. and Seleshi, Y. 2016. Reliability analysis of roof rainwater harvesting systems in a semi-arid region of sub-Saharan Africa: Case study of Mekelle, Ethiopia. *Hydrological Sciences Journal* 61(6): 1135–1140.

Turyagyenda, L. F., Kizito, E. B., Ferguson, M., Baguma, Y., Agaba, M., Harvey, J. J. and Osiru, D. S. 2013. Physiological and molecular characterization of drought responses and identification of candidate tolerance genes in cassava. *AoB plants* 5: 1-17.

Twongyirwe, R., Mfitumukiza, D., Barasa, B., Naggayi, B. R., Odongo, H., Nyakato, V. and Mutoni, G. 2019. Perceived effects of drought on household food security in South-western Uganda: Coping responses and determinants. *Weather and Climate Extreme*s 24: 100201.

Ubisi, N. R., Mafongoya, P. L., Kolanisi, U. and Jiri, O. 2017. Smallholder farmer's perceived effects of climate change on crop production and household livelihoods in rural Limpopo province, South Africa. *Change and Adaptation in Socio-Ecological Systems* 3 (1): 27–38.

Van Leeuwen, M. (2014). Renegotiating customary tenure reform–Land governance reform and tenure security in Uganda. *Land Use Policy* 39: 292–300.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M. and Van Asten, P. 2014. Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability* 8 (0): 15–22.

Wiggins, S. and Sharada, K. 2013. Looking Back, Peering Forward: Food Prices and the Food Price Spike of 2007/08. London: Overseas Development Institute.

Worku, A. A. 2019. Factors affecting diffusion and adoption of agricultural innovations among farmers in Ethiopia case study of Oromia Regional State Western Shewa. *International Journal of Agricultural Extension* 7 (2): 137-147.

Yigezu, A. Y., Mugera, A., El-Shater, T., Aw-Hassan, A., Piggin, C., Haddad, A., Khalil, Y. and Loss, S. 2018. Enhancing adoption of agricultural technologies requiring high initial investment among smallholders. *ScienceDirect* 134: 199–206.

Yosef, B. A. and Asmamaw, D. K. 2015. Rainwater harvesting: An option for dry land agriculture in arid and semi-arid Ethiopia. I*nternational Journal of Water Resources and Environmental Engineering* 7 (2): 17–28.

Zziwa, E., Mugerwa, S., Owoyesigire, B. and Mpairwe, D. R. 2012. Contribution of integrated catchment and surface water management to livestock water productivity in pastoral production systems. *International Journal of Biosciences* 2(5): 52-60.