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Technology and innovation trajectories in the Rwandan Agriculture sector: Are value chains an option?

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Technology and innovation are important in addressing complex problems in the agricultural sector in many developing communities. However, ways and mechanisms to integrate them in the agricultural sector are still a challenge due to the lack of clear pathways and trajectories. Value chains are seen as a strong policy instrument to increase profitability in the agricultural sector; there is also debate around whether value chains can be a potential option to organize technology and innovation trajectories in agriculture. This paper contributes to this debate by exploring the question of how value chain interactions are organized for producing, transferring and using knowledge in the Rwandan agricultural sector. Interviews with relevant value chain actors and a review of reports and scientific literature were used to explore this question. Empirical findings show that value chain structural organization can be an entry point to mainstream technology and innovation. However, this requires building synergies and complementarities among actors. Interactive learning among value chain actors is imperative, with the use of both scientific and indigenous knowledge. Linking value chains to innovation systems is one option to explore for maximizing the potential of value chains in integrating technology and innovation in the agricultural sector.

Keywords: agriculture, innovation, technology transfer, innovation system, value chain

Introduction

Technology and innovation are in many cases considered as important drivers for the agricultural sector development. The promotion of technology and innovation for the agricultural sector is motivated by the need for increasing yield, reduce post-harvest losses and increase the quality of produces (Juma 2015; Schut et al. 2015). This is expected to be achieved by applying technologies and skills for improving practices, inputs as well as market systems. The supply of and demand for agricultural technologies and innovation involve multidimensional interactions among actors. This emphasizes interdependence, networking, social interactions and complementarities among actors (Klerkx and Leeuwis 2008; Madzudzo 2011). All actors (mainly researchers, government and private sector) play significant roles in producing, transferring and using technologies and innovations that are responsive to complex problems in the agriculture sector (Hall, Mytelka, and Oyeyinka 2005; Juma 2015).

The process of producing, availing, accessing and using technologies and innovations is important but it is also challenging. It requires stakeholders' interaction at different stages, particularly for stages of problem identification, solutions finding and adoption of provided technological solutions. This involves complex interactions and proper allocation and use of resources. Approaching these complex interactions and the efficient use of resources requires holistic and systemic mechanisms. All these aim to ensure that provided solutions fit into the context and can sustainably provide positive outcomes. The dissemination and absorption of technological solutions require efficient organization and pathways to channel them through different activities (Chung 2002; Hall, Mytelka, and Oyeyinka 2005; Malerba 2005). However, interactions among these actors require systemic approaches. It is important to create or identify potential avenues for such systemic approaches (Hall, Mytelka, and Oyeyinka 2005).

Innovation Systems (IS) and the Triple Helix Model (THM) are commonly used frameworks to understand how such systemic mechanisms can be organized to meet the intended developmental outcomes, economic growth (Lawton Smith and Leydesdorff 2014; Lundvall 2005). An innovation system is constituted by different elements, which interact in the production, diffusion and use of new and economically useful knowledge. The main elements are organizations and institutions. In the context of IS, organizations are universities, research organizations, government, firms and enterprises. Whereas institutions are the associated economic structures, regulations, rules, law, policies, norms, routines and behaviour among organizations. Interactions and learning within and among organizations are the main processes in IS (Chaminade, Lundvall, and Haneef 2018; Lundvall 2010; Metcalfe and Ramlogan 2008).

To streamline the understanding of these processes, the THM complements the IS. It is used to analyze the relationship between universities, private sector (industries) and government. The THM is a model of the structure to organize empirical analysis of dynamics underlying interactions among and within organizations of the Innovation System. This can be achieved by exploring the key functions of wealth generation, organized knowledge production and organization control that capture cultural and behaviour patterns of actors

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engaged in the interactions involving the production and use of knowledge, which form part of IS (Etzkowitz and Dzisah 2008; Leydesdorff and Etzkowitz 1996; Leydesdorff and Zawdie 2010).

IS exist at different levels, like national, regional and sectoral. The Agricultural Innovation System (AIS) is one of sectoral innovation systems (Baskaran and Muchie 2017; Hall, Mytelka, and Oyeyinka 2005; Lundvall 1998; Malerba 2005). The AIS is considered as a framework to analyze complex problems in the agricultural sector and find ways to provide innovative solutions that improve productivity (Schut et al. 2015). Agriculture commodities' value chains are potential entry points to diagnose these problems. Localization of problems in specific value chains is important in the process of producing needed knowledge and skills to provide innovative solutions (Janssen and Swinnen 2019). However, it requires a more systemic approach due to the nature of problems in the agriculture sector, which are multi-dimensional (soil fertility, crop varieties, pests and crop diseases, post-harvest, market, access to finance and value addition). The multi-dimensional characteristic of agricultural problems involves multi-stakeholder dynamics and interactions at different levels (Farm, cooperative, sector, national, etc.) (Blay-palmer 2005; Madzudzo 2011; Weyori et al. 2018).

The concept of value chain captures a sequence of related and interdependent activities that are undertaken to avail a product or a service through different stages of production and delivery to final consumers, and finally to disposal or recycling. Commodity value chains play important role in organizing interventions that aim at improving profitability in different sectors of the economy, including agriculture (Crescenzi, Pietrobelli, and Rabellotti 2014; Gereffi 1999). They facilitate channelling policy initiatives, diffusion of new technologies, channelling information and allocation of resources (Faborode and Ajayi 2015; Janssen and Swinnen 2019). However, all these are dependent on interactions among value chain actors and their capacity to make a profit out of the available resources (technology, innovation and infrastructure). The organization of value chain activities has implications for relationship building, resource allocation, technology transfer and adoption as well as access to skills and competence development (Gereffi et al. 2001).

A commodity-based value chain is one of the proper ways for organizing and tracing innovation development in the agricultural sector as each value chain may have its special considerations and diversity in ways that activities are performed (Gibbon 2003). It is thus important to understand how value chain structural organization contributes to building production and innovation capacities, particularly in developing countries with emerging innovation systems (Jurowetzki, Lema, and Lundvall 2018). Porter (1985) suggested a basic standard approach to analyze value chains in order to be able to understand key value chain activities at different stages and how value chain actors are involved to undertake these activities. Porter's value chain analysis approach categorizes value chain activities into two main categories, primary activities and support activities. The primary activities include inbound logistics (mainly production activities) and outbound logistics (e.g. processing, packaging and delivery). These primary activities require support activities, where technology and innovation play an important role. Undertaking value chain activities involve interactions among actors through which actors acquire and share skills and competence (Gereffi 1999; Lema, Rabellotti, and Sampath 2018). In this paper, it is contended that the understanding of specific commodity value chain structures and interactions can provide insights on how interactive learning processes can be facilitated for achieving efficient use of technology and innovation to develop the agricultural sector.

From the above point of view, understanding interactions within and among value chains can serve as a basis to understand technology and innovation trajectories within innovation systems. In emerging innovation systems, this can be explored as a co-evolution of value chains and innovation systems. According to Lema, Rabellotti, and Sampath (2018), in principle, this co-evolution builds on the potentials of the two concepts, such as systemic thinking and actions as well as organizational structures and governance. Organizational structures and governance in value chains are potential for developing systemic actions. However, all these require smooth relationships and supporting tools for interactions, which can be explored and experimented through the Triple Helix Model (Leydesdorff and Zawdie 2010). All these are dependent to different conditions and dynamics that in most cases are context-specific. In the context of developing countries, it is important to understand how these concepts can be exploited with their different potentials to facilitate the use of technology and innovation in different economic sectors and for overall socio-economic development.

In the context of Rwanda, the agricultural sector plays an important role in socio-economic development through income generation, provision of food and employment. It contributes around 28% of the national GDP and around 70% of the total population in Rwanda are employed in the agriculture sector, of which 80.2% live in rural areas (NISR 2018, 2019a). Its development vision focuses on a shift from subsistence agriculture to modern market-oriented agriculture. Traditionally, the market was based on exchanging goods among farmers based on the supplies and demands in the communities (Ayalew Ali and Deininger 2014; Bizoza and de Graaff 2012). In this shift, commodities value chains' specialization and land use consolidation are among the major national strategies to transform the agricultural sector in Rwanda. These strategies are used for both subsistence and cash crops (industrial crops) (MINAGRI 2018b; NISR 2019b).

In Rwanda, commodities value chains are associated with regional crop specialization that is mainly based on agro-ecological zones and crops' adaptation. Irish potato, maize, banana and cassava are the main staple crops produced in different parts of the country, with the North-West region as the big producer of potato in the country (around 76% of the national production). Tea and coffee are the main cash crops and contribute

considerably to the Rwandan agriculture export. Coffee is grown in many parts of the country, at both small and large scales. Whereas, tea is grown mainly in South-West and North-West of the country due to its special demand in climatic and soil conditions. Both tea and potato farmers are organized in cooperatives based on farms proximity and market structures (Rutunga et al. 2007; NISR 2019b). With setting priority crops and promoting the value chain approach as a strategy to enhance the agriculture sector performance, technology and innovation became a priority in commodities value chain activities. The development and application of new technologies to increase production and diversifying products are seen as key policy missions in Rwanda (MINAGRI 2018a). However, it remains a challenge to policymakers and other actors that are driving the development of the agricultural sector on how to set trajectories of technology and innovation in the sector. The main challenge is about how to establish operational networks that can allow stakeholders in the value chain to interact and to learn from each other and share resources.

In line with the above discussion, this paper explores the question of '*how are interactions organized among value chain actors for producing, transferring and using technology and innovation in the Rwandan agriculture sector?*' It does so by analyzing how value chain activities and actors' interactions are organized as well as modes of interactions for mainstreaming technology and innovation at different stages of the value chain. Two commodity value chains, namely potato and tea in the North-West region of Rwanda are used as case studies. The paper provides insights on how technology and innovation can be integrated into the agriculture system by using commodities value chains as a point of departure. This paper contributes to the ongoing debate on how a combination of value chains and innovation systems approaches helps to foster understanding of trajectories of learning and innovation in developing countries (Jurowetzki, Lema, and Lundvall 2018; Lema, Rabellotti, and Sampath 2018). Especially in developing countries, this is a living debate in the agriculture sector (cfr Juma 2015; Klerkx and Leeuwis 2008; Madzudzo 2011; Schut et al. 2015).

The rest of this paper is organized as follow. In the next sections, I provide a methodological framework used and present empirical findings that address the research question of this paper. I conclude with a discussion of findings and a conclusion on how value chains can be instrumental to the use of technology and innovation in the agriculture sector. The paper submits to the ongoing debate the view that value chains can be an option to set trajectories for technology and innovation in agriculture. Value chains have an appropriate structural organization for mainstreaming technology and innovation at different stages, and can also serve as a point of departure to build innovation systems in the agriculture sector.

Methodological framework

Data collection

In this study, both primary and secondary data were collected through semi-structured interviews and a structured review of official documents to address the main research question of this paper. Primary data were collected using semi-structured interviews with three main categories of actors. The actors' categories included public agencies, research and academic institutions and the private sector in the Rwandan agriculture sector. Public agencies included ministries and aligned agencies, whereas, research and academic institutions included universities and non-governmental organizations that are directly or indirectly involved in agricultural research. The private sector actors were composed of industries (agro-processors) and farmers; these were particularly from tea and potato value chains in the North-Western region of Rwanda. Interviewees were selected purposively and systematically based on their institutions, their position, seniority and experience. In government institutions, senior policymakers were interviewed. Senior researchers were interviewed in research and academic institutions, whereas cooperative managers were interviewed in farmers' cooperatives. For NGO and private sector, staff in decision-making positions were interviewed.

For each category of actors, an interview guide[1] was developed to guide an interactive discussion between the researcher and the interviewee. An interview lasted between 30 min to 1hour. During the interview, notes were taken and edited later for analysis. The interview guide had an introductory section with the purpose of the study and a request for consent. Prior to each interview, interviewees granted their consent for the interview. The identity of interviewees was kept anonymous and interview notes were handled with confidentiality, only researchers in the team had access to them.

Interviews were conducted from December 2018 to January 2019 with 20 interviewees (4 policymakers, 3 researchers, 8 farmers and 5 from industry). The main themes for interviews included actors' involvement in the value chain activities, sources of innovation and technologies, modes of collaboration among actors, resources allocation and major challenges for technology transfer and adoption. Data from these interviews were supplemented by data from a connected study to this on 'Construction of the National Innovation System in Rwanda: Efforts and Challenges (Yongabo and Göransson 2020).' Data from this study provided additional information on the overall innovation system at the national level and general possible interactions and facilitation mechanisms as well as efforts. These data were collected during the period of December 2017 to February 2018, with 24 interviewees involved in research management and decision making at national level. Primary data were complemented by secondary information from literature and public offices' reports.

Data analysis

Interview notes were organized for their analysis and presentation in a more comprehensive and informative way. A thematic analysis was used to analyze the text in order to respond to the research question of this paper. Text segments were extracted from notes according to main themes for analysis; common trends and differences in interviewees' responses were identified and synthesized. Themes (Table 1) were deducted from IS,

Table 1: Data acquisition and analysis

Data collection		Data analysis	
Primary data	Secondary data	Main themes	Key parameters
Semi-structured interview: Policymakers, researchers, private sector (farmers and processing industries) and NGOs.	**Document analysis:** Policies, programmes, strategic plans, official reports.	Mainstreaming technology and innovation in the value chain, interactions among value chain actors, technology and innovation trajectories in value chains.	Key value chain activities, value chain actors, level of interaction among value chain actors, driving factors for knowledge transfer in value chains, means/mode of interactions for knowledge transfer among value chain actors.

THM and Porters' Value Chain analysis model, as main analytical frameworks for this paper (Etzkowitz and Dzisah 2008; Lawton Smith and Leydesdorff 2014; Lundvall 2010; Porter 1985). Thematic analysis was used to explore on parameters of actors' composition, their activities, their complementarities and diversity, modes of interaction, capabilities, sources of innovation/technologies, potential or existing knowledge demand and supply, avenues of interaction, mechanism and facilitating tools for technology transfer and innovation.

Results

This section presents empirical findings from interviews and secondary information. The section is organized as follow: a) mainstreaming technology and innovation in the value chain activities and actors interactions. Entry points for technology and innovation in value chain activities and value chain actors' interactions and synergies creation are discussed here. b) Technology and innovation trajectories in value chains. Here, I discuss major driving factors for setting paths for technology and innovation in value chains and modes of interactions for knowledge use in value chains.

Mainstreaming technology and innovation in the value chain: Activities and actors interactions

Entry points for technology and innovation in value chain activities

Value chains are used as a policy instrument to develop the agriculture sector in many places. They are used to organize efforts for increasing productivity and profitability in agriculture. Agriculture value chains in Rwanda are generally acknowledged to be short with limited diversification in activities and products. However, they are important in the coordination of key activities that aim at improving the agriculture sector in Rwanda. Based on the value chain analysis conducted using Porter's approach (Porter 1985), as presented in Figure 1, there are '*primary and support activities*' in both value chains (potato and tea in the North-West of Rwanda). Primary activities include '*inbound logistic, outbound logistics, operations, marketing and sales, service and operations*'. The inbound logistics include mainly production activities such as land preparation, farm maintenance, crop protection and other associated activities. The outbound logistics activities mainly focus on harvest collection, processing, packaging and delivery. Marketing and sales activities are pricing, commercialization (including export), and communication-promotion and product diversification based on the market demand. Services are mainly agro-inputs delivery, extension services and training among stakeholders. Operations include standardization and certification, branding and records keeping.

All of these primary activities are supported by support activities that are connected to '*infrastructure development, human resource development, public procurement and technology and innovation development*'. The latter emphasizes agriculture technologies and innovation that address identified problems that affect the yield and quality of produces. Those problems are

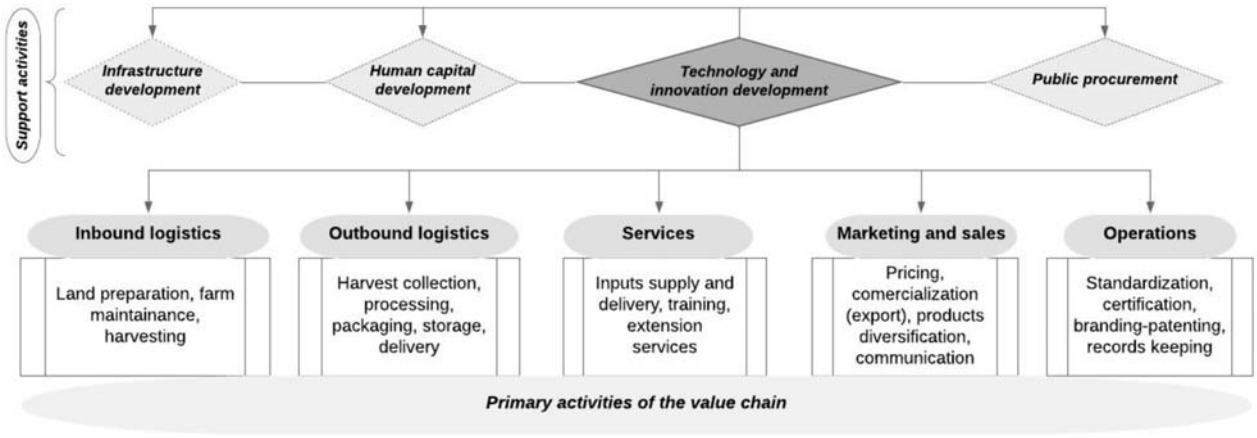

Figure 1: Mainstreaming technology and innovation in value chain activities.
Source: Author's compilation

mainly related to seed production, disease and pest control, fertilizers diversification and their application protocols and post-harvest management technics. Agriculture technologies development and innovation even though are seen as support activities in the value chain, they are key and crosscutting to all activities of the value chain, both primary and support activities. The structure of the value chain allows stakeholders to undertake innovation activities at different stages of the value chain depending on the need for value addition and profit maximization. However, this requires a strong interaction and separation of duties among actors and means to develop synergies and complementarities.

Value chain actors' interactions and synergies creation

Synergies among actors are imperative to maximize profit in the value chain. This can be achieved through collaboration among actors. The main actors in the two analyzed value chains (Figure 2) include farmers who are actively involved in inbound logistics (farm activities mainly) and processors who are engaged in outbound logistics (collection of harvest and post-harvest handling-processing). Government agencies and NGOs are mainly involved in operations and services. Marketing and sales activities are also mainly conducted by government agencies and processors. This is justified by the types of markets in the two value chains.

Potatoes are mainly produced for the local market composed of wholesalers and retailers in different parts of the country. The potato processing plant in the North-West of Rwanda is also a potential market for farmers. Under this market organization, both government and processors are involved in pricing in collaboration with farmers' organizations, mainly cooperatives. For tea, the main market is the international market for processed (semi-processed) tea. However, the tea factory buys the harvest from farmers. The tea factory sets the price for the tea harvest from the farmers, depending on tea price dynamics on the global market. Auction is the popular mode of selling the Rwandan tea at the international market. The interactions among these actors are not yet satisfactory for enabling actors to join efforts and use available capacities to maximize profit out of the use of technology and innovation. As highlighted by one of the interviewed processors:

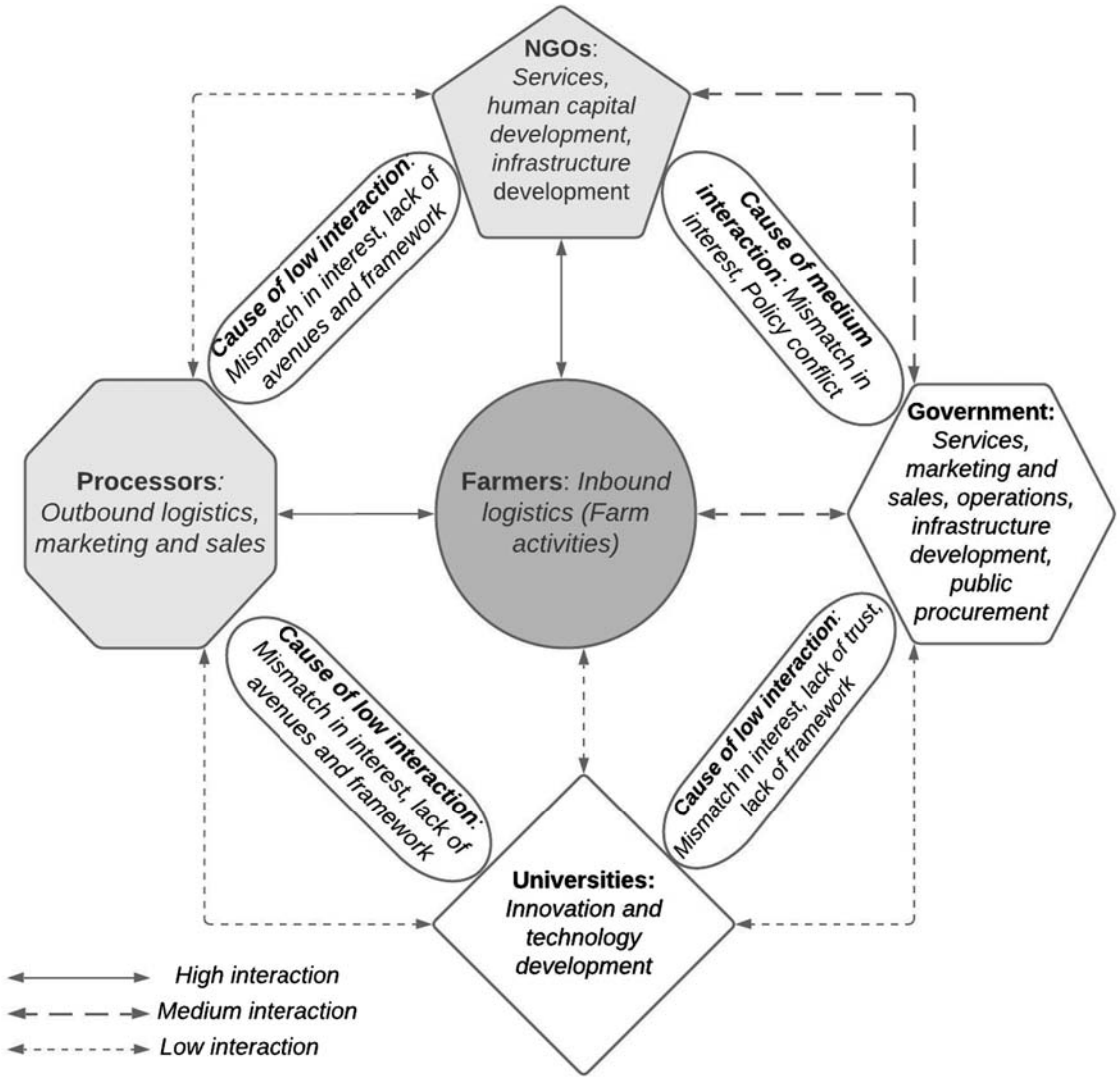

Figure 2: Main interactions among actors and their activities.
Source: Author's compilation.

> I wish that a lot can be done to boost innovation in the Rwandan agriculture sector. But I think the best thing to do is that stakeholders should focus on their core roles and interact for complementarity. Universities should accomplish their role of conducting research and producing the needed human resource. Whereas government agencies, like NAEB, should focus on the facilitation and assistance on issues related to exportation, training, organizing study tours, quality control, certification and standardization as well as associated updates. They should also facilitate the provision of certificates of origin and compensation for local habitat in case their goods are damaged to the expense of promoting market-oriented agriculture or infrastructure development (Processor, tea value chain).

The separation of duties among actors in the analyzed value chains was relatively clear. However, NGOs and public agencies have overlapping interventions in the primary activities that in some cases lead to duplications. To address this, there is a need for systemic and harmonized coordination. For support activities, universities were seen as a key actor in technology and innovation development. Infrastructure development remains the government's responsibilities and investors. The role of NGOs is considerable in the potato value chain compared to the tea value chain. This is explained by the nature of commodities; potato is more for subsistence whereas tea is business-oriented, which is not part of the primary interest of NGOs that are in most of the cases seen as charity organizations.

The role of universities and research institutions in technology and innovation production appears to be less satisfactory compared to expectations from both farmers and processors. There are few collaborative initiatives and there are no remarkable synergies among actors. It is hard to benefit from complementarities and maximization of resource exploitation in the two value chains. This also affects the value addition from technology and innovation as the main support resources. This highlights the need for avenues for interactions among actors to create synergies and complementarities, as pointed out by one of the researchers at the university:

> There is a need for intervention from different actors at all stages; this should start at least with people working together. The interventions should be characterized by complementarity among the value chain segments. Major among the interventions should focus on research, infrastructure, production, processing, policies and regulation. I think that cooperatives can be a good entry point in promoting innovation in the agriculture sector (University Researcher).

Technology and innovation trajectories in value chains

Major driving factors for setting paths for technology and innovation in value chains

There is a common view among interviewed stakeholders and from policy documents that technology and innovation are among major drivers for the agriculture sector development in Rwanda, and are a result of knowledge application for solving identified problems in the sector. However, dynamics in the production and use of knowledge for technology and innovation development may vary depending on various factors. Among major factors are the availability of resources (human and financial), infrastructure, nature of the problem, social structures, interactions as well as knowledge absorption capability of actors. Considering the Rwandan context with limited resources and insufficient infrastructures, it is not easy to rely on one form or source of knowledge for technology and innovation development. All respondents believed that innovation in the Rwandan agriculture sector should rely on the integration of research-based knowledge and traditional (indigenous) knowledge; this might be also supplemented by knowledge/technology importation (Figure 3). The importation of ready-made technology/knowledge is in many cases purpose-driven.

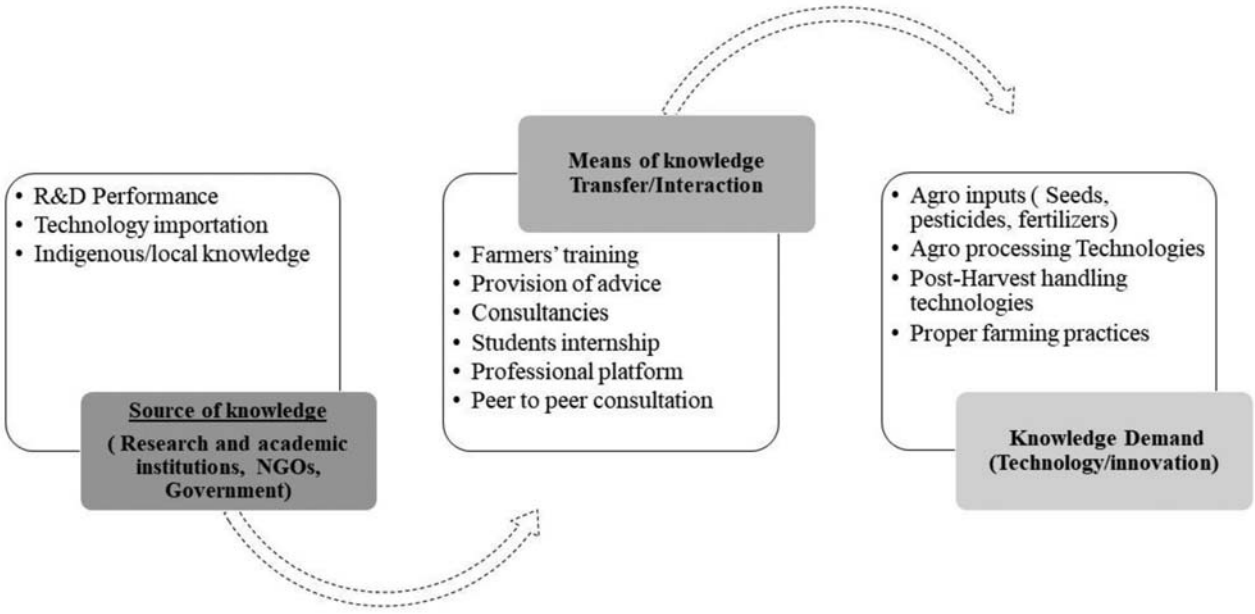

Figure 3: Sources of knowledge and means of interactions to meet the knowledge demands in value chains. ***Source:*** Author's compilation

Either driven by the cost, consumers' preference or specific market demand and performance.

The consideration of research-based knowledge as a priority by many of the interviewed actors (mainly industries and policymakers) emphasizes the need for designing fit-for-purpose research interventions that address real problems in the sector, in the Rwandan context. Proper diagnosis and understanding of major issues in the Rwandan agriculture context were highlighted by interviewees as the entry point for innovation development in the Rwandan agriculture sector. This can set a path for finding appropriate solutions that address complex problems in the sector. However, this appears to be one of the major problems for research-based knowledge production in the Rwandan agriculture sector. Current research efforts are alleged to pay more attention to basic knowledge instead of producing applied and technological knowledge that responds farmers' problems.

From that point of view, there is a quest for practical and transferable knowledge that addresses critical issues faced by technology and innovation end users. Despite the high consideration of research as the key source of needed knowledge, there is a shared view among actors that the research capacity and research outputs are still very low. In addition to this, the dissemination of the little available research outputs is still challenging and hard to establish. Among the underlying reasons for the weak dissemination and uptake of the available research outputs are the limited absorptive capacity of end-users (mainly farmers) and the lack of appropriate tools and structures to overcome that absorptive capacity barrier. The use of appropriate tools that match the learning capability of farmers is still a challenge, as mentioned by one of the cooperative leaders:

> Most of our cooperative members have finished primary school and others did not even go to school. It is hard to convince them to adopt new technology and to teach them how to use it. Most of them cannot even use the technical documents that are given by our partners, like NGOs or RAB (President of potato growers cooperative)

Modes of interactions for knowledge use in value chains

In this section, I provide perceptions from actors in tea and potato value chains on aspects of application of knowledge for a better performance of these value chains, and opportunities and challenges that can be taken into account in the process of facilitating the use of knowledge for technology and innovation development in the Rwandan agriculture sector.

Perceptions from the potato value chain: Based on problems in the potato value chain, both scientific and traditional (indigenous) knowledge have the potential to provide needed solutions. As mentioned by the farmers, major areas for knowledge and skills demand are: farming practices, pests and diseases control, seeds improvement, soil conservation and management and post-harvest handling. Mainly NGOs and farmers' federations are actively engaged in addressing that demand, where farmers are trained in different aspects related to proper farming practices, farm management and cooperative management. In addition to training, other technical supports are provided as well as facilitation for study tours. Farmers expressed high expectations on research and academic institutions. Unfortunately, the current situation shows (Figure 2) low interactions for knowledge sharing/transfer between the academic institutions and other actors in the sector.

There are emerging signs of willingness and efforts to materialize the farmers-universities relationship. This was realized through the case of potato seeds problem, where research and academic institutions in the North-West region of Rwanda collaborated with farmers to provide some solutions. The university conducted research on suitable potato seeds and provided cultivars to seed multipliers. This was appreciated by farmers. In addition to this, more initiatives are emerging, where universities provide advice to farmers and help them to meet the factory quality and safety standards. In most of the initiatives, practical knowledge and technical skills are offered and solicited. This emphasizes the importance of focusing on applied agricultural research. The consideration of traditional knowledge in producing scientific knowledge might be of capital importance as it offers opportunities for relevancy and easy adoption of research outputs by farmers, as they feel that they have contributed to the research outputs.

Processors also expect to acquire the needed knowledge and technologies from universities and other Research and Development (R&D) organizations. This is also due to the lack of R&D units in industries in the potato value chain. The consulted factory during the study relies mainly on technology importation from the Netherlands, mainly due to their established network with the Dutch peers. The factory expressed worries about locally developed technologies in terms of quality and standards. However, the factory believes that there are issues that can be addressed by research that is being conducted at local universities in Rwanda. Generally, there is low recognition of public agencies in providing technical assistance to industries in the potato value chain, while farmers are getting that assistance from public agencies. The role of universities and public agencies should be enhanced in the production and use of knowledge for technology and innovation development in agriculture, as mentioned by one of the potato processors:

> Universities should conduct researches that are responsive to the private sector demand and should do timely dissemination of their research outputs so that companies can access the new knowledge while fresh. The government should consider investing in agriculture and not leaving this to the private sector, which is not even secure in investing in the agriculture sector in Rwanda given the constraints related to climate change, soil fertility and other environmental related issues. There is no strong insurance scheme for agriculture/farming business in Rwanda, and yet this can be one of the solutions in risk-taking for innovation. Better access to finance need to be facilitated as well. (Factory Owner)

Perceptions from the tea value chain: The tea value chain being more business-oriented, actors expressed a high need for technological knowledge for product

diversification and value addition. Processing technologies and technics are major forms of needed knowledge in factories. Tea growers are interested in good farming practices, harvesting technics and good agro-inputs. Tea varieties diversification is also among the top needs of both growers and processors, as current varieties are criticized to be old; this has a considerable impact on the quality and performance of tea products on the market. These needs are expected to be addressed through research conducted at universities and other R&D organizations. For technologies that cannot be produced in Rwanda, processors expect the Rwandan National Agriculture Export Board (NAEB) to facilitate in acquiring them by means of technology importation.

The consulted factory was interested in students' internships as a means of using the knowledge that students acquire at the university. They also consider research-based consultancies as another way to channel the generation and sharing of knowledge between industries and universities. Some works have been done in this framework, like technical assistance in soil sampling and analysis. Another alternative source of knowledge that the factory is interested in is the tea professionals' platform. The platform is interactive but it is still at the early stage and needs to be sustained. With this platform, professionals share experiences and challenges that they face in their daily work. This allows them to join forces and share knowledge to find solutions through peer-to-peer consultation. This can be one of the ways to sustain knowledge use in the value chain, in case key actors are interested to join forces to institutionalize the platform and make it a dynamic institution with regular practices with all the needed support. This shows that interactions among actors for sharing resources, skills and promoting research activities that are responsive to key problems in the value chain should be the central point for promoting technology and innovation in the Rwandan agriculture sector, as highlighted by processors in the tea value chain:

> There is still a lot to be done to increase the innovation propensity in the Rwandan agriculture sector. First of all, there is a need to conduct enough research to address issues in the value chain and the government should play a central role in this. RAB and NAEB are supposed to contribute to this, but so far, it is not clear how they contribute and the solutions that they are providing to farmers. NAEB produces policies but how are they contributing to innovation development? Local industries are not much interested in investing in R&D because they have limited capital and it is not clear to them how this investment can contribute to their business development. (Factory Manager)

Discussion

Based on agriculture value chain activities and actors' interactions, technology and innovation can be mainstreamed at all stages of the value chain. This might be done through 'upgrading' in different dimensions, which is the ultimate goal of the value chain approach. Upgrading for agriculture value chain actors means improving farming and business skills in ways that allow them to capture more of the value in the value chain. Upgrading can increase benefits and/or reduce risks for value chain actors. The upgrading process is based on interaction among actors for learning new skills and adopt improved practices. This can be for process, function and coordination (Cuddeford et al. 2013; Gibbon 2003). Technology and innovation are important for process upgrading in agriculture value chains for improving production processes (better planting materials, irrigation, better pest and disease control technics, etc.), post-harvest handling technics and better marketing. In addition to upgrading, technology and innovation can facilitate coordination among actors by providing efficient communication tools and better service delivery tools. In the context of Rwanda, with upgrading in value chains, technology and innovation can lead to value chain specialization. This is one of the main policy goals for the Rwandan agricultural sector transformation, from subsistence to market orient agriculture. The sequence of value chain activities provides a better structure for adopting different types of technology and innovation at different stages. However, this requires high interactions and synergies among actors at different stages of the value chain.

Complementarities and synergies among actors result from interactions that aim at mutual support to meet a collective interest. In places where interactions are low, innovation propensity is low and it is hard to realize systemic approaches for innovation (Madzudzo 2011; Weyori et al. 2018). For the case of the two analyzed value chains, there are low interactions among farmers and universities. This is mainly due to the lack of shared interest and lack of trust. There is also a lack of appropriate institutional frameworks that stimulate interactions. In places where this relationship (university-farmers) exist, specialized funding instruments and specific policy actions are used to establish and exploit interaction between these two actors. Another underlying reason for low interactions in the two cases but also shared in many agriculture innovation systems in Africa is the mismatch between the knowledge supply and knowledge demand. One option to address this is to introduce the innovation brokering functions to ensure the matching between the knowledge demand and supply. According to Klerkx and Leeuwis (2008) and Madzudzo (2011), innovation brokers can be catalyst individuals or organizations that can articulate the knowledge demand to match the supply or vice-versa. This also can be done by creating networks that help actors to harmonize their interests.

Due to the mismatch between the knowledge demand and supply, in both value chains (tea and potato), knowledge transfer is still a challenge. To address this, there is a need for interactive learning relationships that allow mutual learning to occur. Lundvall (2010) and Jensen et al. (2016) suggest the 'Doing-Using-Interacting' mode of learning as a suitable mode of learning for mutual learning among actors in innovation systems that are not well established, with low R&D capacity. This mode is mainly based on the use and exchange of tacit knowledge, which builds on experience sharing and informal interactions among actors. Considering the Rwandan agriculture sector, this mode of learning can help to respond to the needs of farmers, as they need contextualized technologies that consider the integration of their

traditional knowledge/technologies. Hence, it is important to rethink strategies for knowledge production and transfer in the Rwandan agriculture sector. Ngaboyisonga et al. (2014) suggest the shift from conventional research to participatory research. However, based on empirical evidence in this study, it was observed that this shift needs to be institutionalized and embedded into social structures, mainly including farmers at the early stage of research and engaging them as much as possible so that they feel their importance in the process and own the outputs for implementation. This concurs with Schut et al. (2015) and Mytelka's (2016) suggestions about the social inclusivity of innovation and development strategies for the agriculture innovation system in sub-Saharan Africa.

From this study, interviewees highlighted that lack of trust and leadership among actors, lack of financial capacity, low technological absorptive capacity, mismatch in interest, lack of avenues for interaction and lack of ownership are major underlying reasons for low interactions and key challenges for knowledge transfer. According to Adam et al. (2018), innovation platforms were introduced in Rwanda to deal with these issues and facilitate inclusivity as well as benefits sharing among actors. They have been tried in different value chains, such as irish potato, maize and cassava. However, their level of success was different across regions in Rwanda. For failed innovation platforms, the above reasons were among the root causes. Whereas for successful Innovation Platforms, they acknowledge the role of cooperatives as good channels for interaction and source of leadership as well as organization and harmonization of activities and interest among members of innovation platforms. Thus, it might be reasonable to learn from success stories under the cooperative schemes for the integration of technology and innovation in agriculture. Moreover, the sustainability of innovation platforms needs to get full attention for building a functioning agriculture innovation system. The performance of innovation platforms also varies from one value chain to another and from one type of innovation to another. Innovation Platforms can be among the options to organize interactions among value chain actors within the agriculture innovation system.

Conclusion

This paper explored how value chain activities and actors' interactions are organized for producing, transferring and using knowledge for technology and innovation development in the agriculture sector in Rwanda. By doing so, it contributes to the ongoing debate about how a combination of value chains and innovation systems approaches helps to foster understanding of trajectories of learning and innovation in developing countries, particularly in the agriculture sector.

Empirical findings from this study showed that agriculture commodities value chains offer a structure that can serve as a point of departure for integrating technology and innovation in the agriculture sector. Technology and innovation are essential to all value chain activities and can be mainstreamed at different stages of the value chain. However, this can only be accomplished if there are strong interactions and synergies among value chain actors. In the analyzed value chains, interactions are generally low between universities and other actors. Achieving strong interactions and synergies might require the use of facilitating tools to stimulate and sustain interactions among these actors, like innovation platforms and innovation brokering as suggest by Adam et al. (2018) and Klerkx, Hall, and Leeuwis (2009). This can be applied in the framework of THM. These tools have the potential to stimulating trust, policy coherence, knowledge sharing and efficient allocation and use of resources, if well applied. These tools do not exclude the use of conventional extension techniques; however, they can supplement them and fill the gaps identified in conventional extension services due to the complexities of the problems in the agriculture sector.

Moreover, mainstreaming technology and innovation in value chain structures requires a holistic approach with systemic thinking and actions. A combination of value chains and innovation systems is one of the options that can be explored in this case. Innovation systems can be based on specific technologies, products or regions. The above-suggested tools can serve as instruments to connect value chain patterns to innovation systems components. The application of these tools also might require sustainable mechanisms for human capacity building, for both knowledge producers and knowledge users. Financial capacity and infrastructure are other needed capacities to provide a proper operational environment. Strong collaboration among institutions and harmonized policies and their instruments are key pre-requisite conditions to build these capacities and sustain the value chain-innovation system nexus in the Rwandan agriculture sector.

Based on empirical evidence and conducted analysis, it is concluded that value chains are among the best options to provide structural organization to set trajectories for technology and innovation in the agriculture sector. However, value chains need to be associated with other operational tools and frameworks such as IS and THM. One option to explore for the contextualization of these frameworks is to analyze how major functions like learning and wealth creation can be accomplished and how they fit into a specific context. In the Rwandan context, it was observed that 'knowledge brokering' can be explicitly defined as a function that can facilitate learning. It is recommended for further research to explore how value chains can be connected to innovation systems, taking into account different boundaries and levels of analysis.

Note

1. Interview guides are provided as annexes to this paper.

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Annex I: Interviews guides used in primary data collection

Interview guide for Rwanda for round 1 (December 2017 to February 2018): Key actors (Policymakers, researchers and private sector)

Initiating questions/Points of discussion
1. Are you familiar with the National Innovation System (NIS) concept in your institution? If Yes, what are your views on it?
2. What do you consider as innovation and what are forms of innovation that your institution is interested in?
3. What is your view on how innovations emerge and are disseminated?
4. What are your views on the role of Innovation in achieving the national economic development goals?
5. How do you view the policy and legal frameworks in promoting innovation for development?
6. What socio-economic sectors innovation can contribute the greatest to economic transformation or development goals?
7. With whom does your institution work with for research and innovation matters?
8. How is research and innovation managed in your institution?
9. How does your institution promote the move from research to innovation?
10. What are funding mechanisms for Research and Development (R&D) in your institution?
11. What are mechanisms for funding Innovation activities in your institution?
12. How does your institution facilitate (get involved in or support or promote) the move from Innovation to entrepreneurship?
13. What factors do you think are hindering or slowing the move from innovation to entrepreneurship?
14. What are mechanisms for capacity and competence development for innovation available in your institution?
15. What is one strategy that you think could boost research and innovation uptake in Rwanda?
16. Concluding statement: Is there anything you wish to be done in the future to improve the performance of your institution in R&I promotion and Rwandan NIS development in general?

This interview guide was used in Yongabo and Göransson (2020), a study connected to this paper.

Interview guides for round II (December 2018 to January 2019):

(1) Interview guide for policymakers and researchers in the agriculture sector

Initiating questions
1. What types of innovations do you think are promising in the Rwandan agriculture sector?
2. What do you think are the factors leading to these types of innovations or decision to innovate?
3. How do you find government policies and strategies enabling for innovation development?
4. Who do you think are the key actors to boost innovation in the Rwandan agriculture sector?
5. What do you recognize as major forms of interaction (collaboration frameworks) for these actors?
6. What is the form of knowledge that you consider most important in contributing to innovation development in the Rwandan agriculture sector?
Concluding statement: Is there anything you wish to be done in the future to improve innovation propensity for the actors in the Rwandan agriculture sector?

(2) Interview guide for farmers and processors

Initiating questions/Points of discussion
1. What types of innovations do you think are promising in the Rwandan agriculture sector?
2. What do you think are the factors leading to these types of innovations or decision to innovate?
3. How do you find government policies and strategies enabling for innovation development?
4. What is the form of knowledge that you consider most important in contributing to innovation development in the Rwandan agriculture sector?
Specific for the value chain
1. How do you generally describe the potato/tea value chain in Rwanda?
2. How do you perceive the current industrial development in the value chain (Potato/tea)?
3. What are the major products (tea/potato) and their targeted market?
4. What are the driving factors for your products specialization/ new product development
5. How do you select your technologies to be used in the innovation process?
6. Where do you acquire your technologies and other needed skills to innovate
7. What are your considerations in technology selection?
8. What are your considerations in technology adoption?
9. How is your personnel ready to adopt new technologies?
10. How do you access the new technologies?
11. Who pays (cover the cost) of the new needed technologies
Concluding statement: Is there anything you wish to be done in the future to improve innovation propensity for the actors in the Rwandan agriculture sector?