Fighting Malaria Sustainably: An Investigation of the Innovation System for Biobased Malaria Repellents in East Africa

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ABSTRACT

This paper investigates a biobased innovation system producing a catnip plant-based mosquito repellent developed to fight malaria in East Africa. We adopt a technological innovation system (TIS) methodology. Previous studies on TIS in the global south emphasized innovation diffusion, rather than development. In contrast, we study the catnip-based mosquito repellents in East Africa, a R&D and innovation driven TIS. Our results highlight the potential of innovation development in East Africa by demonstrating strong TIS functions such as entrepreneurial activity, knowledge sharing, and legitimacy building. However, the TIS functions, market creation, resource mobilisation and policy guidance were relatively weak. This suggests that the innovation challenges in East Africa are not always related to a lack of knowledge generation or entrepreneurial capabilities, but more due to a structural feature such as lack of finance, resources, and supportive policies. Our study also demonstrates how local bio-entrepreneurs benefit from business incubation through regional cooperation.

Keywords: Biobased Innovation, TIS, Malaria, Regional Co-operation, East Africa

I. INTRODUCTION

The World Malaria Report (2023) reported 229 million cases of malaria worldwide in 2019. According to their estimation, 94% of these cases and deaths are in Africa, particularly in the sub-Saharan region. Bites of infected female anopheles mosquitoes transmit malaria (Fikadu and Ashenafi, 2023). Many vaccines are being developed and tested against malaria, but the primary efforts are oriented towards prevention. The dominant prevention technique is through the usage of pesticides. However, this latter methodology has a damaging impact on the environment and the health of humans in direct contact. Therefore, the hunt for sustainable and environmentally friendly solutions to fight malaria is needed. Innovations in new antimalaria drugs and preventive disease technologies, especially in Africa, are the key to reducing the malaria disease burden.

In many parts of Africa, including East Africa, multiple prevention techniques have been developed over the years to protect from mosquito bites. One technique is treated mosquito bed nets. The insecticides in the nets repel mosquitoes and other insects. Internal door spraying with insecticides is another prevention measure killing mosquitos that touches sprayed surfaces, but which requires a frequent application to ensure effectiveness. Due to the toxicity of these insecticides, concerns have also emerged about its impact on human health and the environment and the development mosquito's resistance to certain insecticides (Soko et al., 2015).

Local communities have also developed a few practices to repel mosquitoes. Some of these methods are burning dry plants to produce smoke to control the mosquitoes and rubbing the body with essential oils extracted from plants which require frequent re-application to maintain effectiveness. Various methods are used to extract these essential oils where their concentration depends on soil and climate conditions, such as steam distillation, solvent extraction and hydro-distillation (Naseem et al., 2016).

Previous studies have shown that 93% of mosquito bites occur while people are outdoors. Mosquitoes usually target the feet or the ankle. If these body areas are covered, mosquitoes will not bite and seek uncovered hosts (Braack et al., 2015). Most of these bites happen at night, early morning, or evening (Reddy et al., 2011). These findings indicate the need to invest in personal protection to reduce transmission. Different repellent-based products are commercialised for outdoor prevention (Mapossa et al., 2021). These include body sprays, roll-ons, and creams.

In this paper, we are investigating innovation on biobased mosquito repellent products for malaria prevention in East Africa, specifically focusing on Burundi. Innovation can be studied using a range of different tools and models. In this study, we are using the lens of the technological innovation systems (TIS) framework to analyse the strength and weaknesses of this malaria prevention innovation system (IS). The application of the TIS framework on global south countries is not new. However, the focus has been on innovation diffusion rather development (Blum et al., 2015; Kebede & Mitsufuji, 2017). In this paper, we argue against the deterministic view of the global south as recipient of innovation by exploring a case where African entrepreneurs develop inventions, generating and sharing knowledge and conducting R&D activities and exploring pathways for deploying innovations on the market.

We are specifically interested in the factors that stifle or promote an R&D based TIS in the global south. Moreover, based on the lessons learned from this malaria prevention IS, we provide some general recommendations on how to build functional biobased health IS in East Africa.

1.1 Statement of the Problem

To foster development and achieving the Sustainable Development Goals (SDGs) in Sub-Saharan Africa, local innovations addressing local problems and opportunities are of vital importance. However, the pathway for innovations starting from R&D to a product or service having a development impact is very challenging. This is particularly so Sub-Saharan Africa where an enabling environment for innovations are largely lacking. Improving the conditions for local entrepreneurs and innovators to address local health, food security, employment and development needs would thus assist countries in Sub-Saharan Africa to reach their development goals.

1.2 Research Questions

The research questions we are interested in are the following:

i. What are the key components constituting a functional biobased innovation system for developing malaria repellents in eastern Africa?
ii. To what extent can local bio-entrepreneurs benefit from business incubation, knowledge support, and regional cooperation?
iii. What are the barriers and main challenges for upscaling and commercialising biobased health R&D and innovation efforts in eastern Africa?

II. LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Technological Innovation System

The seminal work of Freeman (1987) on innovation systems has attracted researchers, policymakers, and international organisations to the field of innovation, and has led to extensive studies on the functions of innovation systems in the past decade. This attention is due to using of the innovation system as an analytical framework to study and analyse all the social subsystems, actors, and institutions contributing directly or indirectly, intentionally, or unintentionally, to the emergence of innovation (Hekkert et al., 2007). Innovation systems consider innovation socially embedded and the result of a collective process developed through interactions between a multitude of actors. The actors can be individuals and organisations (i.e., firms, suppliers, universities, incubators, and public agencies) who interact within networks (i.e., supplier network, university-industry network) to influence institutions. The interactions are regulated by informal and formal institutions formally and informally (i.e., policies, regulations, laws, culture, and routines).

In this study, we study innovation in biobased health products for malaria prevention in East Africa using the TIS methodology. Carlsson and Stankiewicz, (1991) first introduced the TIS as a broad concept that includes investigating technological aspects of innovation and sheds light on the socio-technical dimension and its impacts on technology diffusion. Moreover, the TIS approach takes technologies as a starting point; hence it is not limited to geographical boundaries, and such systems can be local, national, or global. For this reason, it is widely used in literature.

The TIS framework starts with a conceptualisation of the innovation system as "…a network or networks of agents interacting in a specific technology area under a particular institutional infrastructure [e.g., norms and regulation] to generate, diffuse, and utilise technology…" (Bergek et al. 2008, Heckert et al. 2011). At its heart, the TIS innovation systems structure consists of a) actors and their networks, b) institutions, and c) the technologies themselves and supporting physical infrastructures.

Central to the understanding of the TIS methodology is the analysis of the activities and functions executed by the various actors to identify its key characteristics, such as weaknesses and strengths. Applying the TIS framework to

our case study enables us to conduct an analysis of its function to identify the principal ingredients of the technical system under study and how well it is performing.

2.1.2 Technological Innovation System for Developing Countries

Innovation is a context-specific process that depends on socioeconomic conditions and cumulative learning (Altenburg, 2009). Innovation in developing countries is, thus, different than in developed countries. Contextual factors can be essential constraints on innovation, such as institutional settings (Mendi & Mudida, 2018) as developing countries have less formalised institutional frameworks and less enforceable rules, which cripple the innovation process (Jauhiainen & Hooli, 2017). Previous literature has investigated TIS extensively in the context of developed countries with less attention to its applicability in developing countries where it is more challenging to build R&D, advanced technologies, and radical innovation to compete with developed countries. Researchers and international organisations therefore used the IS framework to study innovation diffusion in recipient least developed countries, differentiating between R&D-based TIS and diffusion-based TIS. The emphasis is on the latter in studies in the least developed countries where the focus is on IS building of absorptive and innovative capacity for further improvement and diffusion of the received technologies (Blum et al., 2015; Kebede & Mitsufuji, 2017).

It has been argued that promoting IS in developing countries should contribute to tackling local communities' problems (Altenburg, 2009). This can be done by developing, disseminating, and adopting incremental, affordable, and inclusive innovations instead of innovating novel technologies for the world. Such inclusive and mature innovations will benefit the disenfranchised populations and contribute to socio-economic sustainability, poverty alleviation, and resilience (Altenburg, 2009; Fagerberg, 2016; Jauhiainen & Hooli, 2017). For this reason, previous literature focused on investigating the functions of IS in developing countries related to diffusion and the utilisation of already established technologies (Agbemabiese et al., 2012; Blum et al., 2015; Tigabu, et al., 2015a; 2015b). However, this focus treated developing countries as innovation receiver's incapable of knowledge or technology creation.

Taking Hekkert et al. (2017) work as a starting point, researchers adapted the TIS and its functions to developing countries' contexts. Edsand (2017) amended the TIS function to include the ability to absorb new technologies and adapt them to the local context including the analysis of global resources mobilisation and informal lobbying (i.e., the public). Kebede & Mitsufuji, 2017, adjusted the knowledge development function to incorporate how knowledge is managed in developing countries through learning by doing, using, and interacting instead of counting the number of patents and scientific publications. There has thus been significant work in adapting the TIS methodology to a developing country context. We present the TIS functions used in this study in table 1.

Table 1

TIS Functions

Function	Descriptions
Knowledge development and diffusion	This function entails the generation of knowledge related to innovation development. Knowledge includes technical expertise and market and business development-related know-how stemming from R&D, imitation, and learning. Know-how diffusion among the IS actors and its evolution in time is also essential dimensions of this function.
Entrepreneurial activity	This function concerns the development and testing of market niches and commercialization of the technology and its applications. This would, for example, include entrepreneurship by private and public sector actors in finding and establishing markets for new products derived from improved sorghum and millet value chains.
Policy guidance	This function concerns the way in which the system is directed in its development, and the factors that shape the directionality of research either through strong overarching industry, or political visions and strategies with coherent policy frameworks. This could include development of new standards stimulating the utilisation of micro-propagation producing disease-free cassava or sweet potato.
Market creation	This function is about creating new markets where technologies can grow. There are three types of market (nursing, bridging and mass-market), and this function describes which stage the market is in and how well it is developed.
Building legitimacy	Legitimacy is associated with acceptance of new technologies or products and compliance with the rules and norms. It encompasses advocacy and support of the new technology. Further, the new technology must be perceived as appropriate and valuable by the users and actors of the TIS so they can generate demand and push market formation.
Resource mobilisation	This function is related to the access and the mobilisation of human, financial capital and all other material and non-material resources and complementary assets needed to develop innovation.

III. METHODOLOGY

To answer the research questions, we implement two rounds of data collection. We reviewed secondary data, grey literature, and internet sources during the first round of data collection to gauge the different stakeholders and map the IS under investigation. For the second round, interviews were conducted virtually between February and June 2021 to deepen the insights collected in the first round of preliminary research.

We interviewed the main stakeholders of the project and researchers and academics involved in the topic. A total of 16 interviews were conducted. The interviews mainly were semi-structured with a list of open-ended questions allowing the experts to elaborate their answers. The project was in the early stage of development, limiting the number of experts involved in the system constraining the sample size. To compensate, we aimed to interview actors along the whole value chain and in the different steps related to the project.

Recent empirical studies investigating IS and their functions used qualitative analysis based on the results of interviews (see, for example, Jauhiainen & Hooli, 2017). Nevertheless, interviews are subject to recall problems as they can generate information on a limited number of events. Hence, to construct the history of the IS, we complement the analysis with historical event analysis. This method retrieves historical events related to technological development from articles, newspapers, reports, and websites. The events are then matched to the different TIS functions, followed by an analysis of the functional build-ups explaining how things changed over time (Huang et al., 2016).

IV. FINDINGS & DISCUSSION

4.1 Describing the Catnip Malaria Repellent Innovation System

4.1.1. The Development of Biobased Repellent from the Catnip Plant

The catnip malaria repellent project (hereinafter called the catnip project) was aimed at developing and commercializing plant-based mosquito repellent in soap, sprays and lotions for East African countries with the main active ingredient derived from the catnip plant. The project's expected outcomes included acceptance, certification and/or registration of the products by the authorities and commercial consumption of products.

The essential oil extracted from the catnip plants works as a repellent to mosquitoes. The oil's primary active ingredient is Nepetalactone, which has insecticidal features and is ten times more effective and more environmentally friendly than the N, N-diethyl-meta-toluamide (DEET), presently used. The catnip plants have other applications. It can be swallowed, applied to the skin, or inhaled. The plant can be used to make tea as a herbal medicine to treat many illnesses such as asthma and nervousness but these benefits were not scientifically proven.

The project started with an entrepreneurial Burundian scientist, deciding to find a solution to malaria disease burdening the people of her community in Burundi and the entire East African region. In 2010, she founded Karire Products a small enterprise in Burundi, focusing on producing health and medicinal products based on available biological resources in the region. She initiated the catnip project while doing her doctoral studies in Canada collaborating with scientists from the chemistry department at the University Polytechnic of Montreal and with a company specialised in essential oils in Quebec called "Aliksir". Coming back to Burundi, she started a production of biobased mosquito repellents and a scaling-up of the catnip project initiated in Canada. Initially, she received support from the French Embassy in Burundi in growing the catnip plants in different climatic conditions, starting with extraction of catnip metabolites and a first formulation of malaria repellents.

The most recent and extensive support to Karire Products came through the BioInnovateAfrica Programme, the largest bioeconomy and bioscience innovation platform in eastern Africa supported by the Swedish International Development Cooperation Agency (SIDA) and based in and implemented by the International Centre of Insect Physiology and Ecology *(icipe)* in Nairobi, Kenya.[1] In 2019, an innovation consortium led by the University of Burundi, teaming up with Karire Products, Gudie Leisure farms, and Jicho Communication, received a three-year Innovation grant from BioInnovateAfrica in the order of USD 750,000 to develop biobased mosquito repellents from plant extracts. The BioInnovateAfrica Catnip project was initiated in 2019 and ended officially in 2021.

To receive the support of BioInnovate, the applicants needed to establish a regional consortium with institutions and actors located in other African countries. In the case of the catnip project, the founder of Karire Products contacted multiple actors to join their expertise and strengthen the development of biobased malaria repellents. These actors included the University of Burundi, involved in the scientific validation of the project through knowledge creation and diffusion; Gudie Leisure farms, a Ugandan social enterprise, working on value chain development, marketing, and business modelling, and Jicho communication, a Tanzanian firm specialising in communications. Along with these actors, Icipe, working on applied research on entomology, supported the project

[1] https://bioinnovate-africa.org/

tasks in knowledge generation, product development, and quality control. In table 2, the actors involved in the project and their role, is described in more detail.

4.1.2 Innovation Actors

The actors in the catnip project IS are described in table 2.

Table 2

The Actors in the Bio-Based Malaria Repellent innovation project in East Africa

Actors	Roles and responsibilities in the Catnip project
Karire Products, Burundi	Karire Products is a social enterprise and the first to introduce a plant-based malaria repellent product from catnip to Burundi. Their duties include cultivating the catnip plant along with the local communities, extracting oils and other vegetable oils, the transformation into commercial products. To conduct these responsibilities, Karire Products established a pilot facility with the support of BioInnovateAfrica (Innovation incubator) for processing, producing and scaling up the products. This pilot facility also aims to foster learning and exchange knowledge about product development. The enterprise was responsible for prototyping the product, collecting raw materials from farmers, and developing its production cycle with other partners and researchers The company has a basic infrastructure and equipment (Gas chromatography, distillation equipment, vegetable oil extractors) for extraction and product development. Karire Products has experience in developing health products from catnip, and other plants. Karire Products also commercialises the products through regional distribution partners.
University of Burundi	The University of Burundi coordinates teams at Faculty of Pure Sciences (Chemistry, Biology) concerned with knowledge creation about ethnobotanical, ecological, herbal medicine research and development, and sustainability of growing the plant and harvesting biological active substances. The teams involved in biodiversity studies identified plant species that can be used as malaria repellent, and initial clinical trials and comparative studies were supposed to be implemented by Faculty of Medicine. At the same time, the Faculty of Economics and Management Sciences was responsible for agricultural and marketing aspects. The University of Burundi Training Hospital and the Public Health Institute (INSP) participated in the project with efficacy testing studies of malaria repellents following guidelines and Ethics Approval from the National Bio-Ethics Board.
Gudie Leisure farms/ R&G investments, Uganda	Gudie Leisure farms is a social enterprise responsible for coordinating the catnip project in Uganda and collaborating on aspects related to value chain development, particularly in marketing, business model development and developing the contract farming framework. They were also charged with identifying local plants species in Uganda that can be cultivated and used for a plant-based repellents such as lavender. Essentially, the Gudie Leisure farms empowers smallholder farmers to become eco-entrepreneurs. They contribute to the project with staff, expertise, office space, experimental farms, marketing, mini processing technologies – distiller and extractor.
Jicho communication, Tanzania	Jicho communication was responsible for coordinating the project and carrying out marketing and media outreach activities through participatory communication workshops and other outreach activities. The aim was to communicate and market the plant-based repellent in the East African region, including in Tanzania.
Icipe	Icipe focuses on entomology R&D, with the aim of improving food security and improving overall health status, Icipe also do R&D and build capacity on the discovery, development and commercialisation of nature-based products. One of their goals is to engage in projects that will add value and contribute with know-how, scientific knowledge, product development (e.g., delivery, drying, distillation and extraction of components and storage), and product quality control. They also work on product branding, packaging, and marketing. The role of Icipe in the catnip project included work on 1) potential strategies for the cultivation and propagation of the plant, (2) investigating how to extract the main active metabolic compound "nepeta" from the plant and (3) testing the efficacy, duration, and potency of nepeta and work on optimising its repellence features. The Icipe involvement aims to provide a consistent product formulation, high product efficacy and safety according to established standards and economically viable production of catnip.

BioInnovateAfrica Programme	BioInnovateAfrica is a regional bioscience innovation platform to promote the bioeconomy in Eastern Africa. The Programme acts as a capacity building platform and bio-business incubator supporting scientists and innovators in the region to link biologically based research ideas, inventions, and technologies to business and the market. The programme focuses on (i) value addition to agro-produce, (ii) conversion of biowaste to useful products and c) biobased health care products. Current BioInnovateAfrica partner countries are Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda. The Programme supports the development of multi-actor innovation consortia, involving scientists, private sector for delivering bioscience innovations. linking biological based research ideas, innovations and technologies to business and markets BioInnovateAfrica also funded the whole catnip project including a support for scaling up malaria repellent production though funding the development of a larger biobased product facility in Bubanza, Burundi enabling Karire Products to expand its production.

4.1.3 Policies and Institutions

Propriety rights and patents play an important role in innovation processes. Some researchers have argued that the patent systems in developing countries are counterproductive for various reasons (Correa et al., 2020). A strong patent system may restrict the competition of domestic and foreign industries in favour of the latter, increasing the prices of food and medicines, disfavouring the poorest communities, and transferring the wealth of domestic consumers buying patented foreign technologies to foreign inventors. Others would argue that patents and national systems for ensuring proprietary rights may foster, incentivise, and accelerate product development and bio-entrepreneurship, attract investments including developing a national private sector able to engage and invest in innovation (Gregg and Pardey,2020). In the case of Burundi, the country has an intellectual property system in place that provides legal protection for inventions, trademarks, and copyrights. The country is also a member of the World Intellectual Property Organization and has enacted laws to protect intellectual property rights, including the Industrial Property Law of 2010 and the Copyright law in 2005.[23] In the case of biological resources, regulations to control the access and use of biological resources are lagging. As pointed out by Oldham & Hall (2013) technical report studying patent data collected in Burundi between 1976 and 2010, they found only one species originating from Burundi mentioned in patent files where the science behind the patent was based on traditional Burundian knowledge. Burundi has however developed a legal framework an access and benefit-sharing system to ensure that the benefits of using genetic resources and traditional knowledge are shared equitably.[4] This is important to protecting the rights of local communities using traditional knowledge for generations which often do not receive any benefits from commercialising bio-resources based on this knowledge. Burundi has also developed a National Biodiversity Strategy and Action Plan (NBSAP) and a law on Biodiversity and Protected Areas[5], enacted in 2017, which is a key instrument and tool for translating the measures set out in the Convention on Biological Diversity (CBD) (UN, 2018). Moreover, the country has a National Biodiversity Committee to oversee the implementation of the CBD. It also created a National Focal Point for Access and Benefit Sharing System (ABS) to facilitate the implementation of the Nagoya Protocol[6]. However, implementing this system is still a challenge.

Developing product and certification standards for biobased health products is essential for promoting their sustainable use the region. Certification and standards for biobased health products serve several important purposes. First, they provide a mechanism to ensure that biobased health products meet specific quality requirements for product performance, safety, efficacy, and consistency. They also help protect consumers by providing reliable information about the safety and efficacy. Certification and standards also play a crucial role for regulatory approvals and market access where regulatory bodies require compliance with specific standards to ensure that products are safe and effective for use. Standards also promote a common set of rules and practices that all manufacturers must follow, ensuring a level playing field. encouraging innovation and improves the overall quality of products in the market and enabling biobased health products to be traded across international borders. In the case of the catnip project, certification standards for biobased health products were lacking. Karire Products. University of Burundi and Icipe therefore actively engaged with the Burundi Bureau of Standards and Quality Control (BBN) to develop a national standard for biobased malaria repellent products and biobased health products in general.

[2] https://wipolex-res.wipo.int/edocs/lexdocs/laws/en/bi/bi005en.html
[3] https://ictpolicyafrica.org/en/document/roimdsjjjlr
[4] https://www.cbd.int/doc/world/bi/bi-nr-02-fr.pdf
[5] Ibid.
[6] https://absch.cbd.int/en/countries/BI

4.2 Strengths and Weaknesses in the Catnip Malaria Repellent Innovation System

In the below section a function analysis the IS of biobased repellent from catnip has been done using the TIS methodology. Our assessment of the strengths of the various functions of the innovations catnip system is shown in table 3. The reasoning behind this analysis is described in section 5.1 to 5.6.

Table 3

Analysis of the Strength of the Biobased Malaria Repellent Innovation Catnip System Based on the TIS Methodology

TIS Function/Score (1-4)	Score 1	Score 2	Score 3	Score 4
	Very poor	Poor	Fair	Good
Entrepreneurial activity				
Knowledge development and diffusion				
Resource mobilisation				
Building legitimacy				
Market creation				
Policy guidance				

Legend:

Score 1: Light grey - Very poor TIS function. The function is not fulfilled, or there are serious weaknesses.
Score 2: Gray - Poor TIS function. While the function is partly fulfilled, there are major weaknesses.
Score 3: Dark grey -Fair TIS function. While the function is broadly fulfilled, there are still weaknesses.
Score 4: Black - Good TIS function. The function is adequately fulfilled.

4.2.1 Entrepreneurial Activity

Karire Products is leading the entrepreneurial activity in the catnip project IS. It has led and pioneered a wide range of activities such as R&D research, product development, commercialization marketing, and business strategy development. They also engaged with farmers cultivating the catnip plant ensuring their inclusion and support for the project and raising the awareness of consumers on the benefits of plant-based malaria repellents.

University of Burundi and Karire Products, together with Icipe in Kenya have all been active in the development of standards and certifications of plant-based malaria repellents. In this endeavour, they engaged with the BBN. This engagement, on different fronts, highlights the central role the catnip project team have had in the value chain and the IS. The role also extends to political entrepreneurship, engaging regulatory government institutions in Burundi to initiate the development of certification standards for biobased health products. Karire Products has led the advocacy for their product by initiating change in regulation to include plant-based products which makes it a pioneer in the regulatory and marketing aspects of the catnip project. Based on these arguments, our assessment of entrepreneurial activity is that it is adequately fulfilled (Score 4) and we accord this function a 4/4 score.

4.2.2 Knowledge Development and Diffusion

Knowledge is central to the technological IS of the catnip-based malaria repellent. The knowledge development to cultivate, distil and extract the high-value metabolites from the catnip plant is led by Karire Products. However, for product development, upscaling, catnip cultivation, the knowledge provided by Icipe was crucial with a role of conducting R&D activities, harmonising the knowledge about the cultivation, the best plant propagation methods by growing in a botanical garden and monitoring their growth and the variation in the chemical component the different growth stages of the plant. The team at Icipe also worked on repellent stability maximising the repellence duration period up to more than 4 hours and thus improving the efficacy of the repellent. Following a successful implementation in Burundi, the aim was to transfer the know-how to the other project actors, Gudie Leisure farms and Jicho Communication in Uganda and Tanzania respectively, for their production of biobased repellent extracted from local plants. However, due to the COVID-19 pandemic and various delays in the process of optimising repellent formulation, that transfer of know-how never materialised. In parallel, the University of Burundi is dedicating a whole set of efforts to identify and study local plants with mosquito repellence characteristics. Besides the development of scientific knowledge within the innovation consortia, the participating actors and institutions also developed technical expertise, business, and marketing know-how, facilitating product commercialisation, and raising awareness among consumers.

An important part of knowledge development has been the development of knowledge enabling the development of certification standards for biobased mosquito repellents. Most of the work here was done by University of Burundi and the Public Health Institute in collaboration with Karire Products and Icipe. As a result, the project has built capacity at the University of Burundi to engage in knowledge generation and data collection for certification of biobased products.

The knowledge development and diffusion within the catnip project was enabled through being part BioInnovateAfrica platform, acting as an innovation incubator, ensured that all project partners were property linked and fulfilled their roles. These collaborations allowed each actor to focus on their core competencies and access the necessary complementary competencies through their network. This collaboration also helped the project to access necessary resources and build a network around their innovation. Therefore, we give this function a score of 3 out 4 because there are still some gaps in knowledge generation and sharing which slowed down progress. Moreover, weak national IP frameworks and inadequate institutional capacity for product certification hampered knowledge sharing further.

4.2.3 Resource Mobilisation

Mobilisation of human, financial capital, material, infrastructure resources and complementary assets are major challenges for innovation in eastern Africa. This is also the case for the catnip project, but the support of the BioInnovateAfrica Programme enabled the project to pool sufficient human capacity to extract valuable metabolic compounds from plants, ensure their quality and transforming them into marketable products.

A specific problem facing the project was the slow procurement of research and processing equipment which, in the region, often relies on import from international providers. It is often very time consuming due inefficient university procurement procedures, delays in obtaining the necessary permits and approvals, long shipping distances, navigating customs regulations and import duties etc. In the case of the catnip project, a slow procurement was one major hurdle slowing down commercializing and upscaling the production within the time frame suggested by BioInnovateAfrica.

Nevertheless, thanks BioInnovateAfrica funding, Karire Products is currently building an essential oils processing facility in Burundi initiating an industrial platform enabling an upscaled production of biobased health products for Burundi and for the region. The Ugandan partner, Gudie Leisure farms also benefited from the project collaborations including raw material supply, publicity connected to the project, business development plans and market analysis. In summary, thanks to the BioInnovateAfrica effort in linking up and funding the different project partners in the region, resource mobilisation can be considered significant.

More human resources with skills in product development, quality control and market development will however be needed to expand this IS and for a larger scale of commercialization. The costs for bringing a product to the market and a successful commercialization is substantial and often far exceeds the initial innovation costs and, in this case, beyond the funding ability of the BioInnovateAfrica Programme. Funding and securing venture capital or loans for commercialization processes is a challenge for most innovation actors, and particularly so in Africa. Commercial credits from local banks are not yet a viable option in the region, due to high interest rates often unaffordable for new enterprises. There is also severe shortage of venture capital in the region to assists innovation consortia, such as in this catnip project, to move products towards commercialisation. Due to limited access of venture capital, limited processing and value chain infrastructure and human capacity in processing, manufacturing, and marketing, we argue that this function is only partly fulfilled and that there are major weaknesses. Thus, we accord this function a 2 out of 4 score.

4.2.4 Building Legitimacy

One of the aims of the catnip project was to include local actors, primarily smallholder growing catnip plants, as active partners in the project. The reliance on local farmers to grow catnip and the investment in R&D to share agricultural knowledge with farmers is building a strong legitimacy for this technology among local stakeholders. Including local farmers in catnip production have given them an additional sources of income, linking them to new value chains and new market opportunities. Besides farmers, the project will eventually, following commercial success, also create new jobs at the Karire Products extraction factory. Karire Products have already hired and will hire more women from the local community for this factory, improving livelihoods and household incomes in the communities where Karire Products are active. Karire Products will also invest in training farmers and factory employees to acquire the necessary knowledge to diversify agriculture and develop new valuable skills. These results imply that the legitimacy function can include aspects related to social inclusion (i.e., farmers, women) and second social capital development by providing sustainable and steady income and investing in marginalised groups in society. At a more general level, the catnip project is contributing to halting the spread of malaria using sustainable and environmentally friendly repellents.

The product substitutes harmful chemical pesticides, and the cultivation of the plant will be based on organic agriculture. The factory will adopt a cascading approach to production, ensuring the minimisation of waste generation and the correct disposal of any waste left. This project orientation to become green in each step is also building legitimacy for biobased green health products based on the local biodiversity in Burundi and East Africa. However, this marketing and building of a narrative on biobased sustainable malaria repellents need to go hand in hand with

market creation and the construction of demand to ensure the success of this IS. In any case, the legitimacy function is very strong in this IS and we accord it a 4/4 score.

4.2.5 Market Creation

Market creation is one of the biggest hurdles entrepreneurs face and only when it is achieved, their innovation can be considered successful as it reaches broader recognition and customer groups. Fully understanding the market demand is therefore crucial in assessing the commercial potential of an innovation. The catnip malaria repellent was developed without a clear and articulated demand for a specific market or market actor, which is often the case with many R&D and innovation projects. Since the market for plant-based malaria repellent is still in its early stage, larger marketing efforts are needed to create this demand for the product. There is also a need for a business and marketing strategy. In the case of the catnip project, the business and marketing strategy development is still in its infancy, and we therefore argue that this function is only partly fulfilled and that there are major weaknesses in the market creation. Thus, we accord this function a 2 out of 4 score.

4.2.6 Policy Guidance

Uncoordinated, incoherent, inadequate, stifling, and conflicting policies are a significant problem for innovation actors in the region. In the case of the catnip project, a major hurdle was the lack of standards and certifications for biobased malaria repellents in Burundi and within the East African Community (EAC), This would include (i) standards for the process in terms of delivery, drying, distillation and extraction of components and storage; (ii) product certification for natural products; (iii) standardisation in terms of the plant cultivation methods. At the beginning and before the involvement of Icipe, the product was tested using the WHO standards, but the project also proactively engaged with the Burundi Bureau of Standards and Quality Control to develop standards and a basis for certification for herbal-based health products. A developed standard and certification mechanism in Burundi could also serve as a basis for the other EAC countries to adopt standards and certification for biobased malaria repellents, facilitating broader market access.

Regarding other regulatory processes, the project did not obtain a sanitary and phytosanitary certificate to produce catnip seeds in Burundi and is growing catnip seedlings in the nursery which delayed exportation to partners to produce catnip in other countries in the region. In Uganda, however, actors started to collect medicinal and aromatic plants to produce vegetable oil, with functional characteristics for the production and marketing of mosquito repellents.

There is also a recent development of more general policies and strategies supporting and regulating science, technology and innovation (STI) supporting innovations in the area of biobased health products. The recently developed EAC Bioeconomy Strategy and the EAC Science Technology and Innovation (STI) and the EAC Intellectual Property (IP) policies are examples. Burundi has not yet developed the legal framework for STI nor a bioeconomy strategy. Its national policy on scientific research and technological innovation ended in 2018 and hasn't been updated and harmonised with the recent EAC STI policy and bioeconomy strategy. A major gap in Burundi and the region is the lack of policies, supportive regulatory frameworks for entrepreneurship in the public sectors, for public-private partnerships and the linking of innovation actors across sectors. More generally, the policies in the regions affecting small and medium enterprises (SMEs) are not conducive to innovation. Much also remains to be done regarding regulatory frameworks and incentives to support and simplify entrepreneurial activities in developing start-up companies. In the case of the catnip project, we therefore argue that this function is only partly fulfilled and that there are major weaknesses. Thus, we accord this function a 2 out of 4 score.

4.3 Discussions

There is no one-fits-all solution for successful innovation. Indeed, there are several possible pathways to success. In this study, we study the development of an R&D-based IS of biobased malaria repellents to learn more about factors that affect, stimulate or stifle biobased innovation in the health sector in East Africa, with a focus on the innovation activities in Burundi.

For the catnip project, some of the key components constituting a functional biobased IS for developing malaria repellents in eastern Africa have been established. However, the functionality of some of these components is not optimal and needs to be strengthened for the IS to be fully functional. Our TIS analysis, evaluating the strengths and weaknesses of the Catnip malaria repellent IS shows that this system is characterized by a strong entrepreneurial activity and legitimacy-building function. This is manifested through the innovative start-up of the project, and its implementation of innovation activities. Advocating and catalyzing commercialization of the biobased malaria repellents through assisting in the development of national norms and regulations is also showing a strong entrepreneurial ability. The project is building its legitimacy by creating jobs, including smallholder farmers and women in the local community. It also adopts and promotes sustainable practices in each step and tackles an important

issue, such as malaria, contributing to building a strong narrative and legitimacy around the project. These are all requirements for a functional IS in the literature (Tigabu et al., 2015).

Another strong function of the project includes knowledge development and diffusion. The project was actively engaged in conducting R&D activity and visualising the importance of collaboration with different actors to develop the necessary knowledge and diffuse it to enhance the adoption and commercialisation of the product. The project has also moved forward in the innovation process, demonstrating the viability of the catnip repellent, a functional value chain and product development pathways. In contradiction with the belief that the TIS in the least developing countries is diffusion-based, this study shows that the TIS in the case of the catnip project is a more R&D-based than diffusion based TIS (Blum et al, 2015; Kebede & Mitsufuji, 2017).

The project also initiated the process of establishing a certification standard with the Burundi Bureau of Standards and Quality Control which is consistent with literature on entrepreneur's role in TIS in lobbying for favourable political instruments (Hekkert et al., 2011). However, so far, none of the products has been certified. The certification will be done based on adequate product samples from the processing factory belonging to Karire Products. Since this factory is still under construction the certification process is pending and dependent of the factory completion and operation. This visualises some the complexities of moving from R&D to commercialization and marketing a product. The catnip project team and the BioInnovateAfrica Programme have nevertheless been able to make a substantial progress on the innovation pathway, from R&D to the market.

The role of Icipe with all its capacity and being a centre of excellence was vital in the project as they provided know-how on various technical aspect of the catnip malaria repellent and its product formulation. This know-how support included (i) catnip cultivation, (ii) extraction of active repellent metabolites from the catnip plants and improved product and (iii) efficacy and improved product formulation with repellent function lasting longer (4-6 hours) in contrast to an earlier formulation lasting shorter (2-3 hours). The BioInnovateAfrica Programme secretariat has also continued to support the project even after the end of the project by interacting with the team and supporting them with advice where necessary and continue looking for funding opportunities for additional capital investments.

The concept and the method by the BioInnovateAfrica Programme, linking various innovation actors with different skills and linking to different in the region has proven very useful for the catnip project and its partners. The role of BioInnovateAfrica is consistent with role of intermediaries and their role in TIS (Lukkarinen et al., 2018). Information regarding technologies, production, value addition and marketing methods has been shared among project partners in building capacity for innovation on biobased health product not only in Burundi but also in Uganda and Tanzania.

The project also had weaker aspects which revolved around resource mobilisation, policy guidance and market creation. These highlight the role of incubators such as the BioInnovateAfrica programme to enable innovation in developing countries. Moreover, these functions also underline the importance of an enabling investment environment, standards, and norms to guide the implementation of new innovative projects and the need for a clear commercialisation strategy to encourage the adoption and diffusion of the product.

The barriers and challenges for the catnip project in terms of upscaling and commercialising of biobased health R&D and innovation efforts is largely generic for the biobased health sector in the region. For the biobased malaria repellent IS, we conclude that while big advances have been made in collaborative research, product and technology development, the innovation is still to be successfully commercialised. The barriers to upscaling, marketing and creating a market demand for the R&D result from the project thus remains. Market demand is central to any innovation and innovations will only be successful if the demand develops alongside the R&D for the product. For the catnip project, weak mechanisms for market feedback during the R&D processes have resulted in an uncertain business case. The catnip project has, as much of the R&D and innovation throughout the region, in search for much needed new malaria prevention technologies, been demand driven but not business driven. A lesson here is that the actors in the catnip project need to do further work on identifying their market segment and how they successfully can access this segment. A clear business strategy with clear marketing and commercialisation solutions and objectives is crucial in building the demand in East Africa for this much needed product.

Another important factor for translating R&D and innovation efforts to tangible and successful products on the market, is the nature and functionality of the relation between academia and the private sector. Public institutions in Eastern Africa are under increasing pressure to deliver tangible products from their research. The problem is that they often lack structures and policies for technology transfer and innovation, such as technology transfer staff, IP policies and management expertise. This limits their ability to establish links with market actors and develop effective contractual agreements**.** Private sector partners can link to public R&D and play an important role in moving R&D to the market through innovation, and there thus is much potential for public-private partnerships in Eastern Africa. However, with the exception of SMEs like Karire Products, few private SME sector actors the region understands the value of R&D and innovation for their businesses. Many of them are risk averse, lack capital, and have an inadequate capacity to innovate and adapt technology and products to local markets. Thus, a close collaboration between

academia and the private sector needs to be catalysed and funded through business bio-incubators and innovation platforms. For the catnip project, the BioInnovateAfrica programme has been crucial in funding the project and ensuring linkages at the regional level between public sector, market, and international research institutions actors, which greatly catalysed the innovation process. However, linking is not enough, there is also a need for incubation mechanisms that ensure all actors are interlinked and supported to play complementary roles. Also, in this regard, the BioInnovateAfrica Programme secretariat played an important role in backstopping and building capacity for the management of the catnip project innovation consortia. While BioInnovateAfrica made a difference in catalysing the catnip-repellent development, it has its limitations when scaling up and commercialising innovation products. Marketing and commercialisation of final catnip repellent products were therefore beyond the support of BioInnovateAfrica.

V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

The biobased malaria repellent project is still considered in an early stage of development, and like any other project, it has both weaknesses and strengths. Ultimately nurturing and strengthening innovation processes, such as the catnip project, requires stable mechanisms and time frames beyond those of the catnip project. At the time of data collection, the funding of the catnip project from the BioInnovateAfrica programme was coming to an end. Largely due to procurement delays of equipment to the essential oils processing facility in Burundi, the project was not able to fully commercialize and get a market response on the biobased malaria repellent products within the project life. This emphasizes the long-term nature of innovation whereas public funding, such as the support from the BioInnovateAfrica Programme, is generally short-term. This is often the case with funding from bilateral aid agencies and public financing regimes, which focus on tangible results and outcomes within a relatively limited project period. It is however unrealistic to expect that much of what can be a 10-15 year innovation process is likely to be achieved within a three-five year period—often the time for which funds are allocated.

5.2 Recommendations

Despite shortcomings, the BioInnovateAfrica Programme has been essential in forging links among key actors at the appropriate time in the innovation cycle. These links will always differ according to the type of technological innovation and whether the innovation will be disseminated through commercial market or, as public good technologies and non-market channels. Nevertheless, as seen in this study, professional incubation services, can greatly assist innovation actors with funding, technology, business and non-market channel incubation. Business incubators can also assist in connecting local private sector actors with international companies and investors bringing in capital, business and marketing models and technologies.

Finally, lack of capital and funding to move products from R&D to the market is a major barrier for all IS in eastern Africa. For innovations on biobased health products to have impact and contribute to better health and livelihoods in the region, a range of funding models for sharing costs and raising venture capital are needed. Government action to assist in mobilising support for innovation from agencies such as development banks, donors and venture capitalists is critical. The donor community may also play an important role by providing funding aid to complement and strengthen investments from other actors.

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