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USER-CENTERED INNOVATION & LOCALIZED RAPID PROTOTYPING FOR AGRICULTURAL TECHNOLOGY CO-DEVELOPMENT WITH WOMEN SMALLHOLDER FARMERS IN MALAWI

VOLUME 1

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Thesis submitted for the Degree of Doctor of Philosophy

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DECLARATION

I, Zewdy Gebremedhin, do honestly declare that this thesis is the result of my own research, and all the content within it is my own. This thesis has not been previously submitted to the National University of Ireland, or any other University as a final requirement for a degree.

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ZEWDY GEBREMEDHIN

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THESIS CHAPTER	SUMMARY OF AUTHOR’S CONTRIBUTIONS TO EACH CHAPTER
Chapter 1: *User-Led Innovation in Agricultural Technology Development and Rapid Prototyping*	Literature review (90%),Writing and Editing (90%)
Chapter 2**:** *Identification of Best-Bet Innovators*	Literature review (85%), Methodology Design (90%), Analysis & Results (100%), Writing (100%), editing (90%).
Chapter 3: *Mapping of Labour, Tools And other Constraints (focus on Women Smallholder Farmers in Malawi)*	Literature review (100%), Methodology Design (100%) Analysis & Results (100%), Writing and Editing (05%)
Chapter 4*: Codesign and Prototyping of Cultivation and Post-Harvest Technologies*	Literature review (100%), Methodology Design (100%) Analysis & Results (100%), Writing and Editing (95%)
Chapter 5: *Field Testing and Analysis of Cultivation and Post-Harvest Agri Technologies*	Literature review (100%), Methodology Design (100%) Analysis & Results (100%), Writing and Editing (95%)
Chapter 6: *Application of Experimental Fitness Tracking Sensors in Agri-Energy Research*	Understanding of sensors (100%), Literature review (100%), Methodology Design (80%), Formulae Development (45%), Analysis & Results (80%), Writing and Editing (90%)
Chapter 7: *Markets and Value Chains for Hand Held Agri Tools in Malawi*	Literature review (100%), Methodology Design (90%), Analysis & Results (100%), Writing and Editing (90%)
Chapter 8 : *Empowerment Effects of User-Driven Design Processes and User-Centered Technologies*	Literature review (100%), Methodology Design (90%), Analysis & Results (100%), Writing and Editing (95%)

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ABBREVIATIONS

2-D	2 Dimensional
3-D	3 Dimensional
AEDC	Agricultural extension development coordinators
AEDO	Agricultural extension development officers
CAD	Computer Aided Design
CADECOM	Catholic Diocese of Mzuzu in Malawi
CIAT	International Center for Tropical Agriculture
CPGs	Community Producer Groups
CRA	Catholic relief services
CW	Concern Worldwide
EPAs	Extension planning areas
FGDs	Focus group discussions
ICT	Information Communication and Technology
KIIs	Key Informant interviews
KJ	Kilo Joules
LN	Low Noise
MoAIWD	Ministry of Agriculture, Irrigation and Water Development
NUIG	National University of Ireland - Galway
PRA	Participatory Rural Appraisal
PRTD	Participatory Research and Technology Development
PTD	Participatory Technology Development
R&D	Research and Development
SHF	Smallholder Farmer
VSLAs	Village Savings and Loans Associations
WR	Wide Range

ABSTRACT

The current challenges and opportunities presented in the agricultural sector in “developing” countries continue to be a paradox. While agriculture forms the backbone of these economies, there are several external factors that present a plethora of bottlenecks for the smallholder farmers who end up realizing little to zero profits due to low productivity. In addition to these external challenges, smallholder farmers are already very attuned to “hard labor” type of field activities that are very labor intensive and time consuming, but which generate little to no benefits. Coupled with land degradation and water scarcity issues that climate shocks can aggravate, smallholder farmers who rely on agriculture for their subsistence and commercial needs remain at a great disadvantage.

As these smallholder farmers are intrinsically aware of their daily challenges in meeting the subsistence needs and their commercial interests, they are best placed to address these challenges given the right tools and an enabling environment. This research investigated the challenges observed in the agricultural sector in Malawi with a special focus on women smallholder farmers who are one of the main sources of labor “human power” for on-farm and off-farm activities. The participatory research interacted with these women smallholder farmers to better understand their on-farm labor challenges as well as their household dynamics, demographics, levels of education, income generation, management of non-farm assets, among other key aspects of their lives. The assessment also involved an analysis of the household and communal labor distribution throughout the unimodal rainy season, as well as mapping the human and physical resources available to them in and around the community.

More specifically, the PhD research conducted an in-depth assessment of these women farmers’ capacity to articulate from a technical/functional point of view, their opinions regarding the existing agricultural tools in Malawi and the suitability of these tools to the labor-intensive activities. In addition, the research attempted to capture their recommended solutions on how to improve the effectiveness of the existing tools. Such an assessment was crucial to capturing an understanding of their key challenges in relation to more sustainable livelihoods, as well as to assess their capacity to resolve these challenges. The assessment revealed the level of capacity needed to adopt new improved ideas to better manage their responsibilities. The research explored the potential of the women smallholder farmers to be innovative in finding their own solutions.

Based on this innovation capacity and environmental assessment, the PhD research also provided a detailed overview of the technology co-design process explored with the “best-bet” innovators to co-develop new and improved agricultural technologies to save time and energy during labor-intensive on-farm activities. In addition, the research investigated the experimental application of Kinematic software sensors to assess energy expenditure when using the existing tools compared to those co-developed by the “best-bet” innovators. A detailed overview of the user-led innovation (bottom-up approaches) has been reviewed in the PhD thesis and arguments made to prove the concept in Malawi. In addition, the PhD research also generated an in-depth overview of the agricultural technology development and production options in Malawi and Southern Africa with an analysis of each of the rapid prototyping options i.e. options that speed up the prototype development process using methods such as 3D printing, local arc welding and metal casting.

Finally, the PhD research also delved into the tool production process and the various challenges that limit the availability of viable productivity enhancing technologies within the manufacturing industry in Malawi. Shortage of electricity and lack of raw materials are just two of the problems the industry faces in the country. The PhD research attempted to investigate available options for rapid prototyping and production of labor-saving agricultural tools. Moreover, the PhD research thesis assessed the markets for agricultural tools in Malawi and the willingness of vendors to sell the improved hand-held technologies co-developed by women farmers in Malawi. The research also captured the willingness of other farmers to procure these tools compared to the existing tools currently in the market.

Based on the research conducted, this PhD thesis attempts to explain the concept of a user-centered co-design process within the context of co-developing labor-saving technologies in Malawi, with women-smallholder innovator farmers who also tested and eventually used these labor-saving and time-saving tools. By using a range of innovative approaches, the tools were tested and an evidence base was developed to prove the concept that women smallholder farmers in “developing” economies such as Malawi can successfully conceptualize, co-design and test agricultural technologies that are tailored to their cropping systems and their needs. To assess any empowerment related gains associated with the research process, the research deployed a women smallholder farmers’ empowerment measuring system adapted from the Women’s Empowerment in Agriculture Index (WEAI). Using this “3D4AgDev-WEAI”, the research investigated whether such an inclusive bottom-up approach could result in higher levels of empowerment, among the women farmers involved, within the context of their agricultural livelihoods.

INTRODUCTION

Smallholder farmers face multiple challenges as they carry out their farming activities in the cultivation period and later in the harvest and post-harvest periods. Smallholder farmers in Malawi typically have little access to any type of mechanized or energy-powered machines and are heavily dependent on human power (Bishop-sambrook, 2005). This is evident in other developing countries as well (Bishop-sambrook, 2005, Ziervogel et al., 2006), where agriculture productivity hasn't been promising (Fulginiti and Perrin, 1998, Fulginiti et al., 2004). However, efforts are being placed to facilitate processes by which farmers are empowered to work together with other stakeholders to design and implement equitable solutions to various development problems (Juliet and Justine, 2016). Participatory technology development is one of the approaches that are currently being facilitated to ensure relevant production of agriculture technology and is a promising user-engaging approach that creates relevant and sustainable technologies by engaging the end-user at the center of the technology development process (Sims and Bentley, 2002, Arevian, 2018).

Altieri et al recommend that in order to sufficiently feed the increasing population of people by 2050, there is an urgent need to adopt the most efficient farming systems and recommend a fundamental shift towards agroecology as a way to boost food production and improve the situation of the poorest. However, most smallholder farmers rely on the most basic tools and implements for their agricultural tasks, of which over 70 per cent are labour intensive (Murray et al, 2014). In addition, a good recommendation was also made by Larson et al that closing the productivity gap between male and female farmers is another way toward achieving the same goal (Larson et al., 2015). Agriculture practices have to change beyond recognition for economic food security and development in Africa. Farmers, particularly women farmers, need to experience massive increase in production as well as labor productivity (Collier and Dercon, 2014).

To achieve this, technologies that enable sustainable and profitable production are very important and research is a key driver of broad-based technological change in smallholder agriculture that may benefit farmers in various ways (Alene and Coulibaly, 2009). Like in many Africa countries, it is uncommon to find mechanized equipment for different farming tasks in Malawi and most smallholder farmers have never actually used or seen one in use (Bishop-sambrook, 2005, Aikins, 2010). There is generally a very low level of knowledge and exposure on the available technologies for agricultural activities that are relevant and can significantly change and reduce their associated labour burdens (Loevinsohn et al., 2013).

In terms of gender differences, there is even lower exposure and lower levels of educations among women smallholder farmers when compared to their male counterparts who face greater challenges and constraints in farming hence low productivity (Backiny-Yetna and McGee, 2015, Aguilar et al., 2014). These women smallholder farmers face major challenges although they contribute to the majority of the farm labour force especially in developing countries where gender roles are more prominent (Doss, 2001, IFAD/FAO/FARMESA, Meinzen-Dick and Quisumbing, 2012, Olusi, 1997) and to the overall household economy (Omari, 1989). However, they do not have access to modern technologies, their own basic tools or the financial resources to secure land (Bank, 2014, Kaarhus, 2010), credit and other assets like drought animals that could reduce the drudgery of their work (Saito et al., 1994).

In 2013, the Bill and Melinda Gates Foundation advertised a call for applications to "Close the Gender Gap" in various sectors that are stereotypically considered male dominated scopes of work. Interestingly, in spite of these stereotypes, women are heavily involved in all levels of work together with their male counterparts and in some cases, end up with larger workloads when their household chores and childcare responsibilities are also considered. To close this gender gap, especially for rural communities where technology infusion is rarely present or accessible, the PhD researcher decided to explore several research questions in carrying out the research in Malawi, Southern Africa.

The overall research goal for this study was to investigate the potential for women smallholder farmers to be engaged in the process of identifying their labour intensive work periods and associated tasks and tools, as well as their ideas for labour-saving innovations. As recommended by other researchers, one of the main objectives was that lessons learned and positive outcomes observed through the research would highlight the benefits of actively engaging smallholder farmer groups to identify the best use of their resources to design innovations that can enable them to be more productive and improve their livelihoods in a sustainable manner (Baldwin et al., 2006, Meinzen-Dick and Quisumbing, 2012, Loevinsohn et al., 2013).

The PhD researcher was hosted by The International Center for Tropical Agriculture (CIAT) in Malawi based on an existing memorandum of understanding with the National University of Ireland Galway. The PhD researcher piloted the 3D4AgDev research at the Chitedze Research Station in Lilongwe, Malawi, where CIAT is based. The research station is managed by the Ministry of Agriculture under the Government of Malawi and research institutions such as CIAT work closely with the Government's

Department of Agricultural Research Services (DARS). The agricultural engineering staff were also consulted in the early stages of these research.

The research sites where women farmers were identified from were in Central and Northern Malawi in Kabudula, Lilongwe District, and in Nkhamenya, Kasungu District. There are four sub-locations in Kabudula that at the time, were under the oversight of Concern Worldwide and three sub-locations in Nkhamenya that at the time, were under the oversight of the Catholic Relief Services, under project management by the Mzuzu Catholic Diocese - CADECOM. The research partnered with these institutions who assisted in identifying key entry points where sensitization meetings and community discussions were conducted preceding the innovator assessment that was conducted to identify innovators. The innovator screening targeting rural innovators who were identified from areas that had limited access to agricultural technologies and the least amount of exposure to mechanization since these communities have similar labour access and energy shortage challenges, coupled with their financial resource limitations.

The overall idea behind technology development is that the task/activity for which the technology is derived or designed for can be better accomplished with technology infusion. The basic tenet behind the development of technologies is that work will be improved as a result of the introduction of mechanized options that are ultimately better for the individual using them. This thesis investigated the potential of these individuals to contribute innovative ideas in a group setting and engaged the end users intensively throughout the research period to generate findings on user-led innovation principles and the benefits seen within technology research and development contexts. In addition to assessing their innovation potential, the research also investigated the feasibility of the innovation design ideas proposed by the women farmers which is described in great detail in chapters 4-5. Chapter 6 offers a complementary assessment on the energy used by women farmers who tested the prototypes and compares them to the existing tools and methods used on energy exertion. The whole thesis attempts to concisely present the research activities conducted over the 2013-2017 period and highlight key findings presented for discussion.

This first chapter provides an introductory review of available literature regarding innovation, its definitions, interpretations and applications in the context of rural agricultural transformation using improved innovations and technologies. It also provides a summary on user-led and user-centered applications for innovative thinking and presents various examples of these approaches and the successes of each.

1. CHAPTER 1: REVIEW - RURAL INNOVATION & RAPID PROTOTYPING

1.1. Innovation Across Various Contexts

The definition of innovation is debated in many contexts, leading to different perspectives (Johnson, 2001). As the overall objective for this research was to assess the feasibility of finding innovative women smallholder farmers who could co-develop labour-saving technologies i.e. time taken and energy used, this introductory review chapter provides an overview for a clearer understanding of general innovation principles in technology development. The focus on the research was specifically on women smallholder farmers as the aim was to research how to close the gender gap in agriculture. In addition, as the research was focused on innovative technology design and application, it was pertinent to carefully identify women farmers who were innovators within their rural agriculture-reliant communities.

The term innovation has several connotations, one of which is that it simply refers to something new and different that is brought into our society to create impact regardless of the field in which it is created (Poirier et al., 2017). Others (Johnson, 2001) define innovation as any alteration in the way the product or service is applied, developed or marketed. Joseph Schumpeter, an Austrian economist in 1934, provided a broader definition saying *"innovation is the commercialization of all new combinations based on the application of new materials and components; the introduction of new processes; the opening of new markets; and the introduction of new organizational forms"* (Boehlje and Bröring, 2011, Janszen, 2000). Others define innovation as the combination of the "technical and business worlds" (Janszen, 2000). Fagerberg cites J. Schumpeter who claimed that when a change to technology occurs, this is an invention while the same change in technology when combined with the business world and made marketable, is now innovation. This raised an important distinction between invention and innovation, where it was stated that invention is the first occurrence of an idea for a new product or process followed by innovation.

Poirier and others have defined innovation as the introduction of something new and different to society with an expected positive impact (Poirier et al., 2017), (Aas and Breunig, 2017, Sontakki and Subash, 2017). Innovation can be regarded as a successful practical application of something new and useful (Neuvo and Ylönen, 2010). Innovation and technologies are not synonymous although these two are interchanged to suit the context. Sumberg highlighted the distinctions between innovation and technologies and cites Noise et al, who describe technology as the production of goods and services, as opposed to innovation that is described as the improvement of the products and services (Niosi et al., 1993),(Sumberg, 2005). Sumberg claims that the distinction made places greater importance on innovation as it encompasses technology but is not necessarily always “driven by it”. More recent literature supports the arguments made by economists since Schumpeter, but argues that the challenge in defining innovation lies in the fact that it is difficult to quantify technological innovation (Kogan et al., 2017). The authors aimed to design a measure of technological innovation that can contribute to economic growth since innovators have diverse socio-economic profiles (Sontakki and Subash, 2017, Kogan et al., 2017).

The definition of innovation can shift remarkably from developed countries to developing economies. Some authors have softened the definition of innovation to account for the activities farmers are doing that may be described as innovative, or at the very least non-conventional (Aas and Breunig, 2017, Janszen, 2000). Researchers seem to concur that there is plenty of untapped knowledge among resource-poor smallholder farmers who are typically not involved in innovative design processes as end users, given that they are slowly being recognized as a resource and not just a beneficiary (Gupta et al., 2003). This rural, resource-limited setting would be the ideal testing of frugal innovations in resource limited environments where the knowledge is rich, but the economies are not well structured/established or do not exist, for various reasons. Frugal innovation is defined as an innovations design process that takes into consideration the needs of the target groups within a resource-limited context with the aim of developing appropriate, adaptable and accessible solutions to address their needs (Basu et al., 2013). It is an innovation process that finds smart innovative solutions with limited availability of resources as is the case in the rural settings the research was set it. Frugal innovation aims to discover new innovative solutions and design products to serve end-users who experience affordability challenges and engage them to do so in a scalable and sustainable approach. This chapter is an introductory section to the overall PhD thesis that aimed to investigate the potential of women farmers to be frugally innovative regardless of their resource limitations in their rural conditions.

While some may critique this definition saying not all innovations have a positive impact, others agree, including Sontakki and Subash who conducted a study (Sontakki and Subash, 2017) and viewed farmer innovations as the basis of adaptability to local problems. User-centered innovation is essential for agricultural and economic development (Bellotti and Rochecouste, 2014, Agarwal and Shah, 2014), especially in today's rapidly changing global and bio-physical environment (Tambo and Wünscher, 2017). For instance, Bellotti and Rochecouste studied farmers' innovations in conservation agriculture by conducting assessments of individual farmer case studies to reveal the specific strengths of farmer innovations and determine the conditions that are necessary to enable farmer innovations to flourish (Bellotti and Rochecouste, 2014).

This first chapter focuses on the investigation of user-centered innovation and the "best-bet" innovators. There is evidence that women smallholder farmers play a major role in agriculture but are prevented from optimizing their performance due to socio economic factors such as lack of access to basic and productive resources as well as climate related shocks among other challenges, as they typically have less access to land and other assets compared to men (Olusi, 1997), (Aly and Shields, 2010). In addition, women farmers tend to have less control of income in their households as seen in several projects assessed through a gender lens (Women's Empowerment in Agriculture Index -WEAI). Other authors have documented that women farmers do not yet have access to similar wages and are not recognized by their male counterparts as equal contributors (Piper, 2005).

The conventional models of "supporting" resource-poor farmers has involved the use of traditional Transfer of Technology models (Omobolanle, 2010). This ToT model regards the smallholder farmer as a passive recipient of new technologies and assumes that a farmer is considered innovative if he/she accepts the technology that is passed on to her/him. While this model has demonstrated some successes for resource-abundant farmers who can afford to take risks, there is little evidence that it works well in resource-poor contexts (Chambers, 2014, Chambers and Ghildyal, 1985, Chambers and Jiggins, 1987). These authors instead argue that the "farmer first and last" user-centered design approach should be the preferred model as it is more socially-inclusive and shows proof of higher adoption by farmers in resource-poor contexts (Murray, Gebremedhin, et al., 2016). This farmer-first and farmer-focused approach requires end-users to show initiative, creativity and take ownership of the process, leaving the decision making in their hands and ultimately leading to sustainable outcomes. It is this participatory technology approach that was investigated in this PhD research piloted in rural Malawi.

Research on farmer innovations claim that farmers have been innovating for as long as humans have consumed plants and animals (Sontakki and Subash, 2017). Macmillan and Benton claim that any sustainable farming system must have farmers as the center of the innovative design process (MacMillan and Benton, 2014). While this acceptance of farmer-led research and innovation is slowly improving, there is still little done to measure exactly how much of farmer-led innovation is taken into account by "experts" in research or what innovations exist at the grassroots levels (Beckford et al., 2007). This thesis aims to investigate the innovator potential among women smallholder farmers and how this can be applied in the low-income contexts in rural, agriculture-reliant communities.

1.2. Closed Innovation or Open Innovation?

Most conventional innovation processes assume closed principles where the innovation process is targeted to the end user for final delivery but not during the research and development of the innovation itself. On the other hand, this research opted to explore the open innovation principles of embracing all capacities from partners and incorporating any existing innovations that had the potential to be tailored to the end-users demands. By leveraging existing innovations and locally available resources, the research investigated whether the proposed approach was feasible. As Penin suggests (Penin, 2011), the open innovation theory is likely more suited to the innovations in the pipeline, where the main goal is to integrate all ideas from all users rather than alienate any potential contributors. Table 1 is a summary of the contradictory principles that define open and closed innovation approaches, adapted from "The New Imperative for Creating and Profiting from Technology" (Chesbrough, 2003).

Table 1-1: Contradictions of Open and Closed Innovation- adapted from Chesbrough 2013.

Closed Innovation Principles	Open Innovation Principles
• The smart people in our field work for our institution.	• Not all smart people work for us. We need to work with smart people inside and outside our institution.
• For effective agricultural R&D, we must discover the innovation, develop it & disseminate it ourselves.	• Externally sourced R&D can create significant value; internal R&D is needed to claim some portion of that value.
• The institution that gets an innovation to market first will win.	• Building a better business model is more important than getting to market first.
• If we create the most and the best ideas in the sector, we will win.	• If we make the best use of internal and external ideas, we will win.
• We should control our innovation processes so that competitors don't profit from our ideas.	• We should generate value from others' use of our innovations and leverage the innovations of others whenever it advances our business model.

1.3. ICT and Group Dynamics in Innovation

Information Communication and Technology (ICT) is quickly shifting the balance of power between service providers and end-users of innovations. With the advent of ICT based innovation processes social media i.e. Instagram, Twitter, Facebook and others, inventors now have access to a wider client base and can refine innovations based on client experiences. The service provider is endorsed by the number of followers interested in the innovation. This premise supports one of the research questions that this thesis explored i.e. is there an increased benefit in engaging potential end-users in the innovation identification in an individual or group innovation process? ICT driven "democratization of knowledge" has catalyzed the private sector to include end-users in the innovation process as it is evident that end-users bring added valuable inputs and can improve the innovation research process significantly. Private sector actors incorporating user-centered initiatives include but are not limited to Intel, Lego, Google and Microsoft who actively engage end-users as part of the R&D process to test and share feedback that is therefore incorporated to align the innovations to client/end-user demands.

1.4. User-Driven/User-Centered Innovation

User-centered innovation is the process of harnessing the final product's user's knowledge to co-develop new/improved products, services and concepts. A user-driven innovation process is based on an understanding of true user's needs and a more systematic and participatory involvement of end-users. User-centered innovation facilitates a shift from supply-driven approach to a more demand-driven "bottom-up" approach. This definition can also be interchangeably referred to as User-led or User-oriented, Participatory design and more recently Participatory Technology Development (PTD).

Neuvo and Ylönen expressed the importance of viewing innovation as a cultural process through which new concepts and meanings can be created(Neuvo and Ylönen, 2010). According to Rosted, user-centered innovation aims to increase the utility value of a given product while others define user-centered innovation as a cooperation between service provider and user to co-design, which has been found to result in more innovative ideas when compared to the conventional approach (Rosted, 2005) (Mitchell et al., 2015). The most unsustainable innovation is viewed through the lens of the producer, where end-users are perceived to play a peripheral role in the use of sustainable products and services developed by "experts" (Nielsen et al., 2016). Tietze and others claim that separation of ownership can control negative impacts on user innovation capacities (Tietze et al., 2015). Lakhani and Panetta on the other hand, argue that user-centered innovation has been promoted through the evolution of “distributed innovation processes” where more than one source of innovation may exist that is neither linear nor hierarchical (Lakhani and Panetta, 2007).

While other research studies aim to determine how to facilitate innovation as policies change over time some authors highlight how innovation capability is ambiguously treated in literature despite the positive relationship that exists between the implementation of innovation and the future performance of an organization (Rubach et al., 2017), (Aas and Breunig, 2017), (Bogers et al., 2010). Through a mutually beneficial process, “co-creation” can be a successful strategy for this research to tap into the user innovativeness and test their capacity to innovate while at the same time, users often can willingly participate in the co-designing process to address their own needs, to influence the innovation process, but also out of intrinsic motivations and expected rewards, create ownership of the conceptualized innovations (Gustafsson et al., 2012).

Regardless of the terminology used, it has become widely accepted that the end-user must be actively involved in the innovation process for products and services to be improved to meet the needs of the aforementioned end-user. This was also investigated through this research to determine whether these target groups i.e. end-users of agricultural technologies, could successfully be engaged as co-designers of labour-saving technologies.

1.5. Defining Characteristics of Innovators Among End-Users

While some research argues that one has to invent something new to be considered innovative, others consider refinements to existing ideas as equally innovative (Regan, 2016) (Poirier et al., 2017, Fagerberg, 2003). What is clear is that the definition is subjective to interpretation and therefore researchers must be careful not to underemphasize the definition of innovation and what it means to be an innovator. Many of the characteristics that determine innovators based on the context and research dating back to 1958 have similar findings (Avermaete, 1 March 2003) (Hildebrand and Partenheimer, 1958, Adesina and Zinnah, 1993, Loy Jr, 1969, Rogers, 1961, Rogers, 1959). The typical innovator has been described as one having;

- *Higher levels of education,*
- *Higher income earnings or potential,*
- *Larger land holding capacity,*
- *More access to and participating in more in extension services,*
- *Direct access to scientists to get new information,*
- *Greater exposure to learn new practices*

However, there is another school of thought that believes the minds at the margins should not be considered to be necessarily the marginal minds (Gupta et al., 2003, Critchley, 2000). The argument made by these authors is that illiterate, low income individuals from rural communities can be successful innovators based on their indigenous expertise passed down from ancestors. The key difference is whether the "innovators" were given an enabling environment in which they could innovate. The role that end-users play in innovation development is not well captured and has been in the past unacknowledged effectively (Beckford et al., 2007), (Sontakki and Subash, 2017). The importance of recognizing farmers as innovators is critical and must begin with identifying and fostering innovators. Several articles have presented diverse sets of characteristics for identifying innovators but on average, most suggest that farmer innovators are interested in trying out new ways of doing things, have leadership qualities and voluntarily participate in extension services and NGO projects (Rogers, 1961, Lagnevik, 2005, Rogers, 1959).

Understanding of the diversity of smallholder farm households is critical for the success of development interventions (Makate and Mango, 2017). There are some barriers that constrain innovators' ability to translate investment into new products (Pellegrino and Savona, 2017), whether it is mainly finance, as most of the literature would suggest, or whether it is mostly knowledge and market-related aspects. For researchers to successfully facilitate the process of innovation, they first need to take into consideration the context of the end-user and their environment (Wettasinha et al., Undated). This research focused on identifying "best-bet" innovators among a group of women farmers and describes innovators in the agricultural context.

1.6. Participatory Research and Technology Development (PRTD)

While there are still many limiting factors to making research completely user-driven/centered, frugal innovation may be possible in developing countries where resources are typically limited. MacMillan and Benton have also highlighted the benefits of such an approach for research and development in the agricultural sector where smallholders have limited resources at their disposal (MacMillan and Benton, 2014). In spite of this, there is still the perception that smallholder farmers are on the receiving end of innovations once developed externally (Tambo, 2015). Several authors have proposed that a farmer-engaged participatory approach is a basic facet to successful innovation in the agricultural sector (Lehto, 2012) (Ashby and Sperling, 1995). This enables fostering the innovations which are key to enabling transition towards new business, technological and policy models that address different challenges in attaining sustainable results. (Brunori et al., 2013) Frugal innovation processes enables the active engagement of resource limited smallholder farmers to be at the center of the technology research and development process to ensure that their valuable inputs are well captured even in resource limited conditions.

Other authors have researched the alternative to the farmer participatory research approach, the technology transfer model (Rusike et al., 2006), where smallholder farmers recipients of the outputs of the innovation process but are not part of, and cite this approach as one of the causes for little impact/low uptake seen at the grassroots level (Gonsalves et al., 2005). While these authors state that this transfer of technology model has worked well to deliver agricultural technologies, there is lack of concrete evidence that sustainable impact achieved through this approach (Douthwaite et al., 2002, Glover et al., 2016). Researchers argue that this typical "one size fits all" approach simplifies the intricacies of different contexts and inaccurately implies that one solution can be applied to any setting (Chang, 2009) (Glover S. T., 2019). This study aimed to investigate this argument and tailor the technology development process with the smallholders farmers as central experts to guide the R&D process so as to customize the technologies to their cropping systems and community needs.

In most sub-Saharan countries, the technology-driven productivity growth plans have largely failed (Hounkonnou et al., 2012). Participatory research has been more effective as described by Jennings who assessed it over contemporary extension practices (Jennings, 2005). This research as well as other work done by Glover et al, highlight the alternatives to the transfer of technology process and argue that involving the farmers at the inception stage creates a better environment for the farmers to adopt co-developed technologies and have ownership and accountability over them after the project has ended (Glover et al., 2016), (Glover D, 2019). This approach demonstrates a higher likelihood for sustainable technology uptake and adoption compared to transferring technologies and demonstrates that farmers' perceptions of ownership and accountability are also as important as the cost-benefit analysis factors of the technologies themselves.

Eiser et al. (2012) state that these factors and other intrinsic rewards are more determining factors of technology adoption besides the cost-benefit analysis that is typically applied and these findings are supported by many researchers (Glover S. &., 2016, Andersson, 2014). While the importance of these financial analysis cannot be understated, it is clear that decision-making regarding technology uptake and adoption is a more multifaceted and dynamic "double-edged sword" in the technology paradigm that has many dissemination pathways (Van Hulst, 2016, Glover D. &., Policy 82, 2019).

1.7. Gender in Participatory Research and Innovation

Particular attention must be given to women smallholder farmers who have less access to resources as compared to their male farmers (Saito et al., 1994). As women farmers make significant contributions in agriculture, their inputs as end-users must also be considered (Doss, 2001, IFAD/FAO/FARMESA). What is clear is that agricultural technology development benefits more when all farmers are engaged throughout the PRTD process (Tambo and Wünscher, 2015). To boost productivity, both male and female smallholder farmers must be better engaged as the end-users to identify their challenges and be part of the problem-solving process. As intermediaries, researchers have the opportunity to engage smallholder farmers in participatory technology development to highlight the challenges that require innovative thinking and transform the farmers' ideas into feasible concepts (Douthwaite et al., 2002, Bao Huy, 2002). Doss emphasizes that although the actual figures for women farmers' amount of food contribution is not known, what is known is that women farmers should be engaged as they are significant contributors to agricultural productivity and therefore equipped to contribute their ideas and suggest innovations for labor-saving concepts (Doss, 2010).

Saito et al (Saito et al., 1994) states that as women farmers do most of the work, they must be given the opportunity to make their value-adding contributions. Through this "engaged" innovation process, farmers have the opportunity to contribute their ideas, conduct on-farm testing and provide recommendations for refinements that will consequently enable the transfer knowledge to each other to develop technologies that can boost their on-farm efficiency (Ashby and Sperling, 1995, Glover et al., 2016). Based on the literature review conducted, this PhD research opted to test the hypothesis that a user-centered innovation process combined with rapid prototyping options, could be harnessed into the development of labour-saving technologies with women smallholder farmers that would be tailored to their specific challenges in the agricultural sector and farming systems.

1.8. Women Smallholder Farmers in the Malawian Agricultural Context

According to Malawi Government (GoM), the agriculture sector produces 90 per cent of net earnings that in particular contributes 30 per cent to the country's Gross Domestic Product (GDP) (Agri-Malawi Magazine, 2020). Smallholder farmers in Malawi comprise of an estimated 2 million households who cultivate about 4.5 million ha of land. 25 per cent of smallholder farmers use less than 0.5 hectares and only 14 per cent cultivate more than 2.0 hectares. Smallholder production in Malawi is generally characterized by subsistence farming, low input and output levels, poor quality control, limited value addition and weak market links, thus low commercialization of the produce (World Bank Country Profile, 2020). However, smallholders still produce about 80 per cent of Malawi's food. Malawian agriculture is further marked by gender inequalities and is currently ranked 67th out of 144 countries in the Global Hunger 2016 Index with score of 0.7 (Welt Hunger Hilfe et al., 2016).

Although recent research has questioned the much acclaimed "fact" that women produce 60-80 per cent of the food, the same research agrees that female farmers make significant contributions to food production and are more constrained by limited access to and control of agricultural resources such as improved tools, land, credit, extension services and access to markets (Doss, 2010). Without these resources, women farmers cannot be expected to boost their labour productivity and will remain in the poverty traps they currently are in.

As a result of the Malawi government's (GoM) policy priorities and limited fiscal space, support for women farmers to access mechanized and improved agricultural technologies has been stifled, making this a primary challenge for the overall agri-productivity in the country. In addition, unsuitable agronomic practices, lack of quality tools and implements, pests and diseases, environmental degradation and erosion, adverse weather conditions and use of poor-quality seed/planting materials altogether contribute to low agricultural productivity levels. Research and extension services in Malawi are very linear and "silo" based and are working in isolation further exasperating the already low technology adoption rates. previous research and development projects supporting extension services to smallholder farmers have noted the many challenges for the extension advisory services and more importantly for the smallholder farmers.

Typically, women farmers in Malawi have fewer opportunities to get access to technical expertise on the best agricultural productivity boosting techniques. Advisory services lack the necessary information to customize the extension services to the needs of the women smallholder farmer (Bank, 2014). The existing linear model of technology dissemination has failed to generate the envisioned impacts, as these services in Malawi are currently not sufficiently oriented towards the needs and requirements of a modernizing agricultural sector. The market for local manufacturing has been growing exponentially, yet over the past 25-30 years very little improvement has been seen in terms of increase in technology development. The most affected is the agriculture sector, which is widely seen as traditional by all existing farmers and even more so with youth entrepreneurs and private sector players. Most smallholder farmers only have access to the most basic tools such as the traditional hoe and lack customized tools for their various on-farm activities, most of which are quite labor intensive (Sims and Kienzle, 2006). This research aimed to assess any improvements in the local manufacturing of labour-saving technologies.

There is a large gap in connecting smallholder farmers to the most effective and efficient resources to boost their agricultural labor productivity. Women smallholder farmers especially face these challenges as they are the major labour component for agricultural households (Saito et al., 1994). For example, in Malawi, Niger, Uganda and Northern Nigeria, women farmers have access to lower levels of agricultural inputs that men do. This gender difference accounts for more than 80 per cent of the gender gap in productivity in Malawi (World Bank, 2014). Although recent research suggests that women smallholder farmers actually "make up fewer than half of the number of people who are reported as economically active in agriculture" (Doss, 2010), what is clear is that there is gap in the data available on those unseen who are "economically active in agriculture".

While some research proposes that new technologies increase labor burdens, (Suda, 1996), women farmers' ownership of technologies would increase their levels of empowerment i.e. control over assets, finances and access to credit as well as overall decision-making capabilities. Based on empowerment models such as the Women's Empowerment in Agriculture Index-WEAI) (Alkire et al., 2013), this research would measure the gains of having improved technologies and assess them to see if the process of being engaged in technology development is empowering for the women farmers. Without these labour-saving technologies, women farmers will continue to rely on the existing labour intensive farming systems and will likely remain in the cycle of perpetual poverty. These will continue to have lasting effects on the health and income levels on the household and community at large. Furthermore, women farmers lacking improved agricultural technologies will consequently have agri-productivity enhancing constraints that will impact the country's economic growth. This research aims to address this key challenge in Malawi through the user-centered technology co-development approach outlined in the chapters to follow.

The research investigated the potential of linking user-centered innovation concepts from women farmers to the design and development of labor-saving technologies suited to the end user's cropping systems and identified requirements. It was therefore necessary to first understand the concept of user-centered innovation and potential categories of innovators before selecting them from the rural communities of Malawi. Some research claims that a group of individuals can be categorized based on how they react to innovation. (Petrík et al., Moore, 1999) categorized them into those who are technology enthusiasts, visionaries, pragmatic conservatives and skeptics and noted the gaps (chasm) that exist between the innovators and non-innovators.

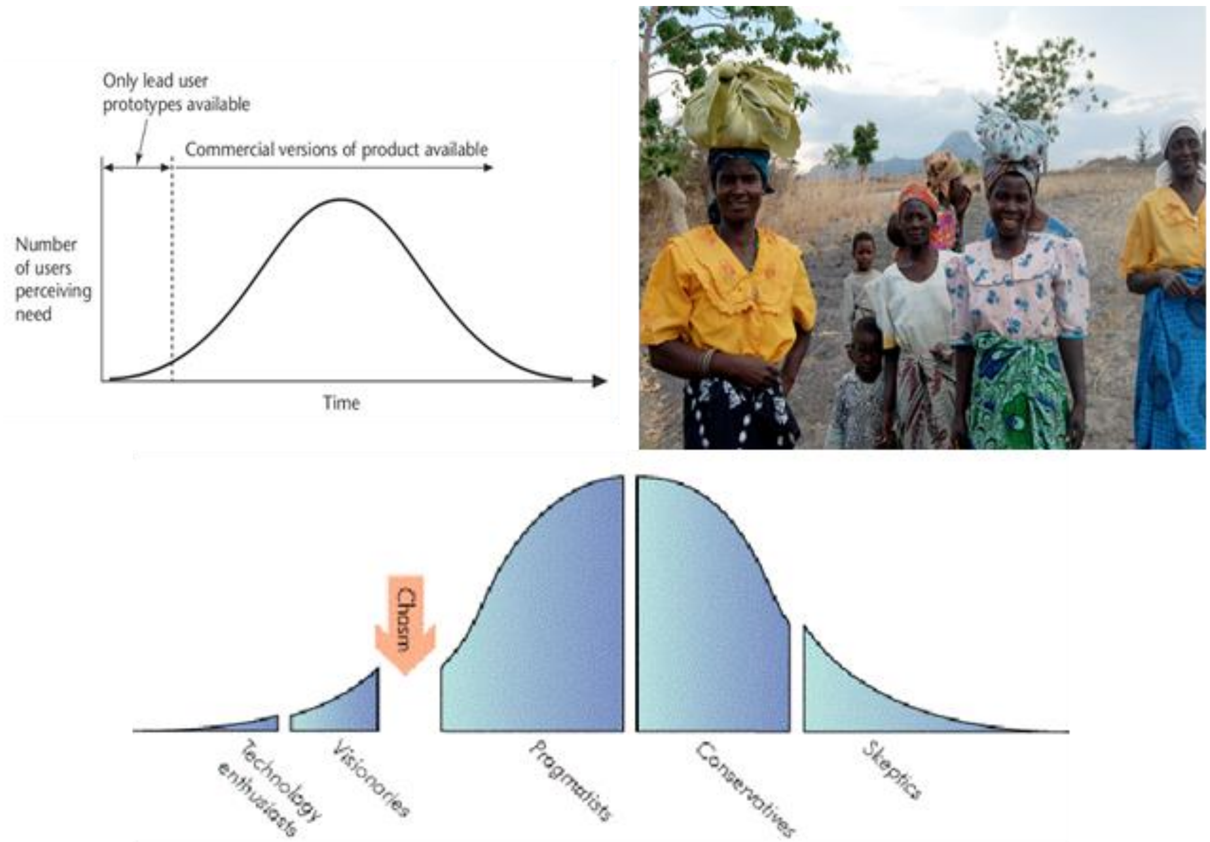


Figure 1-1: Reactions to Innovation (Petrik et al.) Reproduced from original source.

Figure 1-1 above explains that a small portion of the population i.e. the technology enthusiasts and visionaries, get excited and foresee the importance of innovation than the majority of the population i.e. the pragmatics, conservatives and skeptics. The subsequent chapters provide an in-depth overview of the activities conducted to identify best-bet innovators which for the purpose of this research are defined as the individuals within a certain area/group who demonstrate innovative characteristics and have a higher chance of innovating as compared to their counterparts. These are the technology enthusiasts and visionaries within the rural context of Malawi, with a focus on the rural woman smallholder farmer. Figure 1b below provides a summary of all the research activities conducted during this study to test the concept of user-centered/user-driven innovation and rapid prototyping to solve key agricultural labour challenges for women farmers and their households in Malawi.

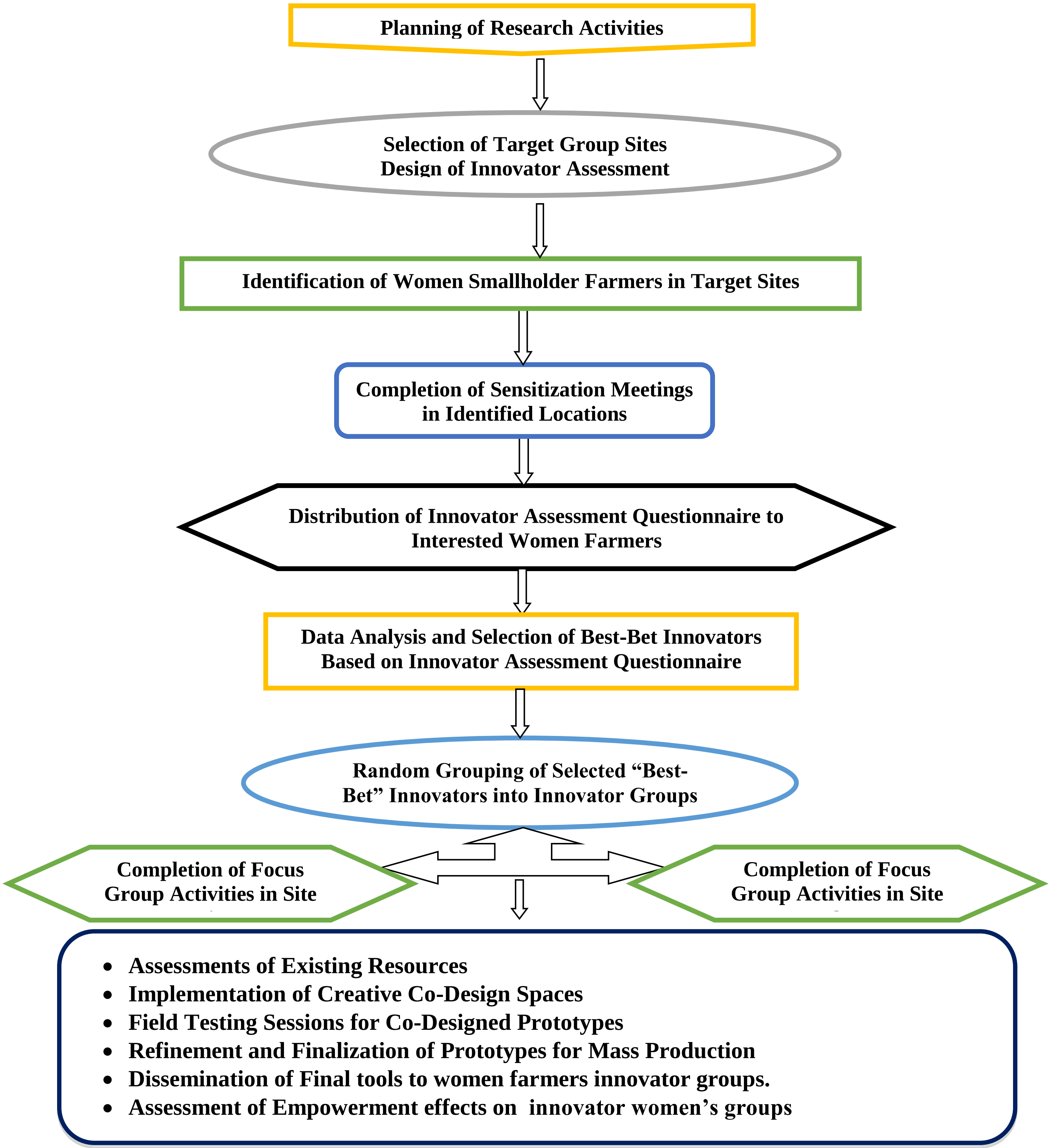


Figure 1b Summary of all PhD research activities conducted in Malawi

2. CHAPTER 2: SELECTION OF "BEST-BET" RURAL INNOVATORS

2.1. Research Objective

The research objective was to:

- *identify and group best-bet innovators amongst women smallholder farmers in Malawi who demonstrated the highest potential to conceptualize, design and adopt labor-saving technologies tailored to the demands of their cropping systems.*

This chapter describes the applied methodology that was specifically developed for this research to identify "best-bet" innovators from rural communities.

2.2. Research Methodology

2.2.1 Study Location

The research was conducted in rural communities of Malawi due to the high percentage of women who contribute to the agricultural labor force. The actual sites were chosen based on entry points identified by existing partners as well as based on the high levels of poverty, heavy reliance on agriculture for subsistence and income generation. The PhD researcher was hosted by The International Center for Tropical Agriculture (CIAT) in Malawi and piloted the 3D4AgDev research at the Chitedze Research Station in Lilongwe, Malawi. The research sites where women farmers were identified from were in Central and Northern Malawi in Kabudula, Lilongwe District, and in Nkhamenya, Kasungu District. There are four sub-locations in Kabudula that at the time, were under the oversight of Concern Worldwide and three sub-locations in Nkhamenya that at the time, were under the oversight of the Catholic Relief Services. The research partners with these institutions who assisted in identifying entry points where the innovator assessment was conducted. Rural innovators were also identified from areas that had the least amount of exposure to mechanization since these communities have similar labour access and energy shortage challenges, coupled with their financial resource limitations. The table 2 below summarizes the locations where in Malawi the innovator screening exercise was conducted.

Table 2-1:Locations Selected for Innovator Assessment - 3D4AgDev Screening Sites.

REGION	SITE	LOCATION	GPS Coordinates		GROUPS
			Latitude	Longitude	
Central	Kabudula	Chitukula	33.75000	-13.7830	C, D, E
		Kalumba/Msanama	33.53100	-13.7680	A
		Lukira	33.53469	-13.81364	B
		Mkuta I & II	33.58351	-13.7638	F, G, H
Northern	Nkhamenya	Kavikula	33.42998	-12.5694	I, J, K
		Lodjwa	33.52500	-12.4110	M, L
		Kavidebwere	33.55326	-12.5267	N, O, P

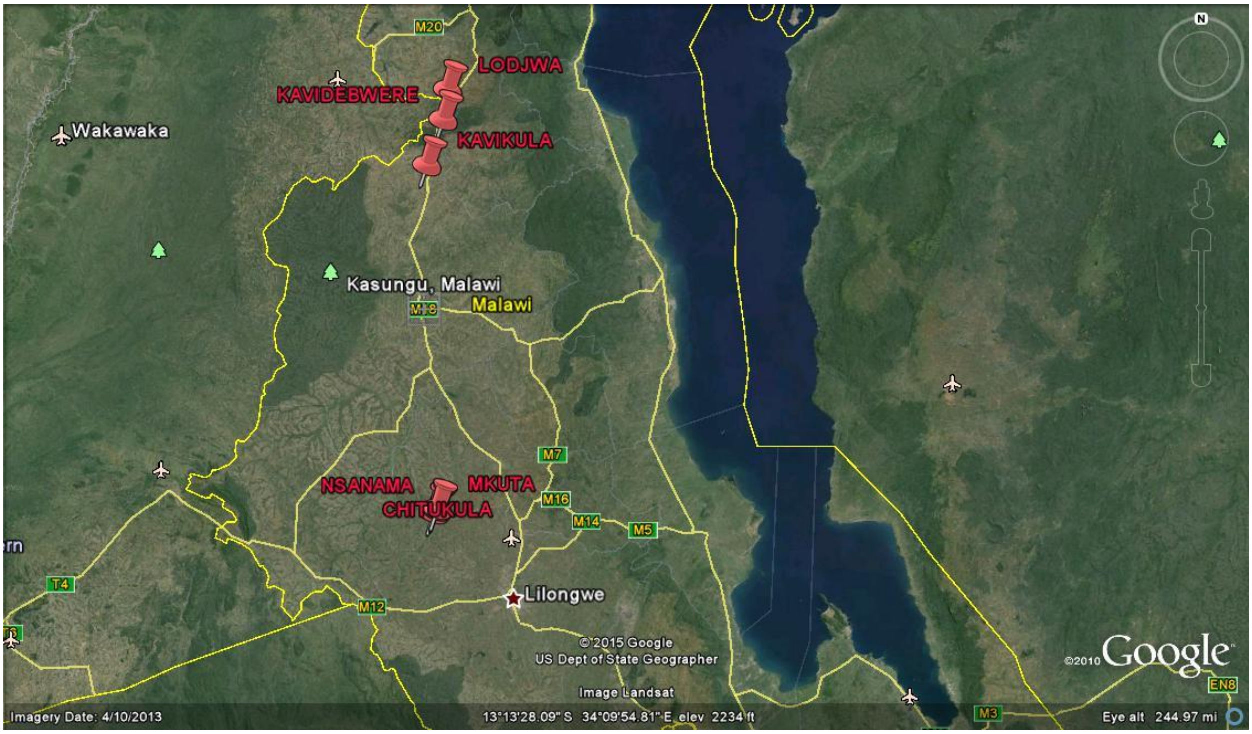


Figure 2-1: Mapping of Research Sites as per table 2-1.

2.2.2 Sampling Technique

Through the support of the key partners mentioned above, interested women farmers were invited to sensitization meetings where the research team explained the nature of the project and the expectations highlighting the participatory nature of the activities. Their interest was critical as they would be involved on average 2-hour focus group discussions (FGDs) per week and should have a personal interest that would result in active exchange during the FGDs. There were 1607 women farmers who took part in the sensitization meetings, which estimates a minimal sampling of one farmer for every hundred farmers. The study applied purposive sampling techniques as described by (Dolores and Tongco, 2007), since the research objective was to select women smallholder farmers only. This approach was fundamental to ensuring good quality of data gathered by ensuring reliability and competence of the persons trained to gather the information (Dolores and Tongco, 2007, Dooley, 2006). Participants in the innovator screening were chosen from a list of female farmers that were also working with international Non-Governmental Organizations (iNGOs) in pre-formed groups such as:

Villages, Savings and Loans (VSLAs) Groups

Villages, Savings and Loans (VSLAs) Groups are made up of 10-25 smallholder farmers and are formed based on proximity of members. This informal saving groups enable them to have access to credit facilities with very low interest rates and without collateral (Karlan et al., 2017) as VSLAs are often the only financial option for low-income households in Sub-Saharan Africa (Hendricks and Chidiac, 2011). The groups are self-managed and have a structured reporting system with a chair, secretary, treasurer and members. They form the VSLAs based on informal group agreements and in very few cases, have a constitution and a register of members. They meet to make contributions, borrow funds or for marketing/trading days.

Consumer Producer Groups (CPGs)

These are groups of 25-45 smallholder farmers who form self-managed groups with the aim of collectively purchasing inputs and implements as well as selling bulk produce. CPGs give farmers a higher purchasing power as they are better positioned to negotiate better prices for their harvests. The groups are run by members based on a voting system and also have a structured reporting system with a chair, secretary, treasurer and members. They also form their groups entirely based on informal group agreements and in fewer cases have a constitution and a register of members. They meet regularly to make and record contributions, take out and record loans and share profits.

2.2.3 Innovator Criteria & Innovator Questionnaire Design

The innovation screening criteria developed took into consideration several factors observed from the literature review in chapter 1 and through the sensitization meetings and consultations with other innovator assessment researchers. The survey was conducted with adherence to all field research, integrity and country protocols and was impartial, transparent and reliable. The scoring criteria developed was used to score each respondent in the same manner using pre-coded responses that were used to clean and analyze the data collected in the innovator identification survey. The innovator screening forms were completed by women farmers in Malawi with support from village community agents and field officers who were trained on how to complete the forms. The screening resulted in the selection of women smallholder farmers who scored above the cut-off score on the innovator assessment scale.

The research liaised with a range of experts on grassroots innovation (Wettasinha et al., Undated, Douthwaite et al., 2002, Gupta et al., 2003, Hossain, 2016) during the process of developing an innovator screening tool to distinguish between high innovator scoring farmers and low innovator scoring farmers. An innovator assessment questionnaire survey was designed consisting of 55 questions, out of which 39 questions were actually scored to assess for innovation potential. The survey included questions capturing baseline data as well as questions that aimed to segment the audience by assessing personal and financial profiles, early adoption of technology, entrepreneurship potential and farming practices which are some of the characteristics of innovators as described by previous authors (Poirier et al., 2017, Swim, 2017, Wettasinha et al., Undated, Fursov et al., 2017). As Smith et al explains, , it would be beneficial to identify the best-bet innovators from the group of the female farmers in Malawi i.e. generators of new practices and tools and experimenters who possess the highest potential to conceptualize labor-saving technologies tailored to the demands of their cropping systems (Smith and Findeis, 2013). Patterson and Zibarras called them trait-based measures of creativity and innovation potential and their results suggest that openness to experience is positively related to creativity and innovation and the same observation was supported by Fursov et al (Patterson and Zibarras, 2017) (Fursov et al., 2017).

The research also considered that the innovative potential is an emergent property of processes and groups, rather than an individual characteristic and aimed to clearly identify innovators using a customized sampling approach. The initial questionnaire comprised of six sections that were designed to assess the respondent's personal potential for early adoption of technology, entrepreneurship potential, and knowledge of other smallholder farmers who demonstrated innovative thinking and pioneered activities accordingly. The questionnaire also captured the respondents' household baseline data on assets, access to credit and financial services**.**

2.2.4 Engagement of Women Farmers During Innovator Screening

With the initial draft of the innovator-screening questionnaire ready, the research was able to pre-test it internally for credibility and reliability and aimed to roll out the survey using a purposive sampling technique using a snowball approach to reach as many women farmers who belonged to a self-formed and self-managed group. Community agents and field officers were recruited as enumerators from the villages where the screening survey was administered. Each enumerator received training on how to collect the data required and distinguish between relevant and irrelevant data for each question asked and special attention was given during the training sessions to ensure that the integrity of the data collection was not comprised. The questionnaire was pretested in all sites and corrections were made to finalize the screening questionnaire and scoring database.

Each trained field officer and community agent collected data and completed one innovation screening questionnaire with each individual woman smallholder farmer who was willing to participate in the research activities. Each screening exercise took an average of 25 minutes per respondent. Each screening sheet was completed in local dialect using the official language in Malawi (Chichewa) and was then translated through manual data entry by site to record all farmer personal identification, household data, farming details, source of income, early adopter indicators, access to assets and financial services among other criteria.

The procedure for selecting women as "best-bet innovators" formed the basis for this research on bottom-up approaches to agri-technology development and aimed to identify women farmers who, in spite of their low income and resource limited environment, have the innovative capacity to share their contributions in an open and inclusive innovative creative space that was provided by the research. The sampling method involved a combination of deductive and inductive elements where the target innovator was a female smallholder farmer first and an innovative one who could be grouped with other similar/likeminded, confident women. The research considered criteria that would remove any bias in selection of the women farmers to be involved in a participatory design/innovation process. The aim of the study was to identify innovators among the marginalized and excluded "poorer" and disadvantaged farmers who are systematically left out of the innovation cycle in the technology AR4D process. The research aspires to overcome these systemic challenges and directly targeted women smallholders' farmers from a low income, resource limited, unmechanized agricultural context.

2.2.5 Parameters for User-Centered Agri-Technology Development

Once the groups of "best-bet" rural innovators were identified and organized, the following parameters were enforced to ensure the active participation in the project and productive deliverables for each group:

Time Logged to Capture Participants' Commitments

The research was initiated in direct response to the call for applications to "Close the Gender Gap" in agricultural productivity through the development of labour-saving technologies that are tailored to the woman smallholder farmer's daily cropping needs. As opposed to the traditional "incentive-based" participation approach, this research captured the time and inputs of each woman innovator with the long-term objective that each of the women smallholder farmers who participated in the design, testing and refinement of labour-saving technologies would receive a set of labour-saving tools as an in-kind compensation for their time and contributions to the research activities to be used over a year during which an impact assessment would be conducted to measure long term effects of the co-developed technologies.

During each discussion with the women smallholder farmers innovator groups, the research facilitator logged the total time given by each woman innovator which enabled the research to capture the total time given by each participant and as a group. This would be crucial information needed to accurately log the contributions for the women innovator groups to receive the final labour-saving technologies that were developed. The research note taker recorded the level of participation for each group and as individuals. It was important to capture the most actively participating women farmers who shared their ideas and made contributions towards the design and testing of new farmer-designed labour-saving tools. These women farmers were later identified as peer-motivators that would promote uptake of technologies and long-term adoption.

Group Innovation Dynamics

There is significant research supporting the idea of working with groups as a way to generate more creativity and from an economic perspective, working with groups has been proven to be an effective way to empower individuals to work together towards an economically beneficial solution (Karlan et al., 2017, Hendricks and Chidiac, 2011, Ngendello et al., 2000). This research proposed that organizing women smallholder farmers into groups enabled the groups to share and contribute their ideas in an enabling environment. This approach was taken strategically to enable access to a diverse range of knowledge since according to some authors (Sontakki and Subash, 2017, Tambo and Wünscher, 2015, Reij and Waters-Bayer, 2001), innovators have diverse socio-economic profile. The applied selection procedure and the group-based working methodology was combined to maximize the chances of identifying women farmers who were in a better position to engage with the research to achieve the aims of the project. The research considered whether to engage existing groups but after careful consideration, retained the innovator assessment process as this component was a strong aspect of the empowerment process thought the research. The women farmers who passed would be expected to display higher levels of confidence and self-assurance post-assessment if they passed.

There was significant interest from women farmers to be part of the technology development process but due to budget limitations, 187 women smallholder farmers were selected from a larger cohort of 1607 screened farmers. These farmers were organized into small focus groups of 10-12 women per group. The PhD researcher was the lead facilitator while the research interpreter/notetaker took notes from the discussions that were in local dialect. The facilitator took personal notes in English based on the translations provided to be used to verify the notes from the interpreter.

The research employed participatory research methodologies such as FGDs, activity clock exercises, seasonal calendar group sessions, resource mapping and in-depth panel discussions to break down labour distribution in the household among other considerations in the research. The findings are a direct output of constant and inclusive interactions with the women farmers, which is synonymous with other research that supports participatory methods when working with smallholder farmer groups (Twomlow et al., 2002, Lilja et al., 2001, Jennings, 2005, Gonsalves et al., 2005).

Consent Forms

Once the screening was completed and the best-bet innovators were identified, the researcher visited and met with the selected women farmers, traditional authorities, chiefs and local community members to brief the community on the project goals and expectations for the upcoming months. All the selected "best-bet" women smallholder farmer innovators who were to participate were informed explicitly that they had successfully passed the screening process and this gave them the confidence to work within the innovator groups they were placed in. All the women who participated in the research activities were asked for their verbal consent and also completed voluntary consent forms to confirm their understanding of their roles. The consent forms clearly indicated that their participation was voluntary and for the mutual benefit of the smallholder farmers and their communities as well as for the research to answer the research questions. The local field officers and community agents assisted the smallholder farmers who were unable to read or write to understand the contents of the consent form. In all interactions with the women smallholder farmers, the local language was used to ensure that there was no miscommunication or misinterpretation of the research objectives and expectations.

2.2.6 Data Analysis Methodology

Screening and scoring of the innovator identification survey was done using excel spreadsheets and analysis was done using SPSS in addition to MS Excel. Of the selected 192 screened innovators, 5 farmer questionnaires were actually disqualified as men completed them. The researchers therefore worked with a total of 187 women smallholder farmers divided into 16 randomly grouped sets of women innovators. The details of this are described in the results section.

ArcMap 10.3.1

This software was used in the development of the maps of the project sites to locate the 187 best-bet innovators who were identified through the innovator screening survey.

SPSS and MS Excel

From the responses of the women farmers using the innovator screening survey questions, the research cleaned the data and separated data sets for each innovation identification question. Based on a scoring system, the women whose responses demonstrated innovation potential were selected as the best-bet innovators. A cross-tabulation exercise was done using SPSS version 22 to compare the frequencies of women farmers with respect to their groups (above-score as Accepted and below-score as Rejected). Results were organized in excel where percentages of responses by category were calculated to represent the data using histograms that show the proportion of respondents with respect to their scores. The analysis in SPSS also involved descriptive statistics, where frequencies for the variables were also completed. Multiple response analysis was conducted to come up with frequencies of responses. Excel was also used to summarize research outputs in tables and represent the data in charts and compare findings.

2.3. Results

The questionnaire had a scoring system designed to calculate an overall innovator score for each survey participant. Using this approach 12 per cent (187 of 1607) of the surveyed population was selected as the best- bet innovator group. The average score for the above-score category was 23 points out of 55. The research investigated whether the sample size (n=187) is representative of the surveyed population (N=1607), assessed the geographical and demographic representativeness in addition to their similarities in household characteristics e.g. similar land ownership characteristics, similar crops and planting materials, among other noted characteristics. It was observed that the sample representing the above-score group were drawn from a population above 65 per cent i.e. 65% of the population in each of the sites responded to the innovator screening survey and their populations were normally distributed.

Table 2-2: Representation of Women Farmers Scores by Sub-Location

Site	Max Score
Lodjwa	24 (43%)
Kavikula	37 (67%)
Kavidebwere	36 (65%)
Lukira	12 (22%)
Chitukula	31 (56%)
Mkuta 1	25 (45%)
Mkuta 2	12 (22%)
Kalumba	10 (18%)
Average	23 (42%)
Total	**187**

2.3.1 Analysis of Survey Responses for Innovation Capacity

Each of the screening questions that were used to assess innovation is presented in this section with interpretation of the collected data.

How many of your children go to full time schooling? (Question 1.8 of innovator survey):

The figure below shows that more respondents from the above-score category i.e. those selected as innovators, send their children and particularly, their girl-child to school, The results suggest that we can expect more girl-children from the innovator cohort attending school compared to the below-score cohort indicating an unconventional mind-set for those who indicated that their girl-child was in school or in the case where there were no girl-children, those who sent all their boy-children to school as opposed to sending them to work on the farm or tend to cattle also showed innovation potential i.e. they displayed a different mindset from most farmers in the community who would tend to keep their children at home to help with household and farming activities rather than giving them the education that would expand their options in life. This question enabled the research to capture the respondents who demonstrated higher capacity to do things differently compared to other members of the community.

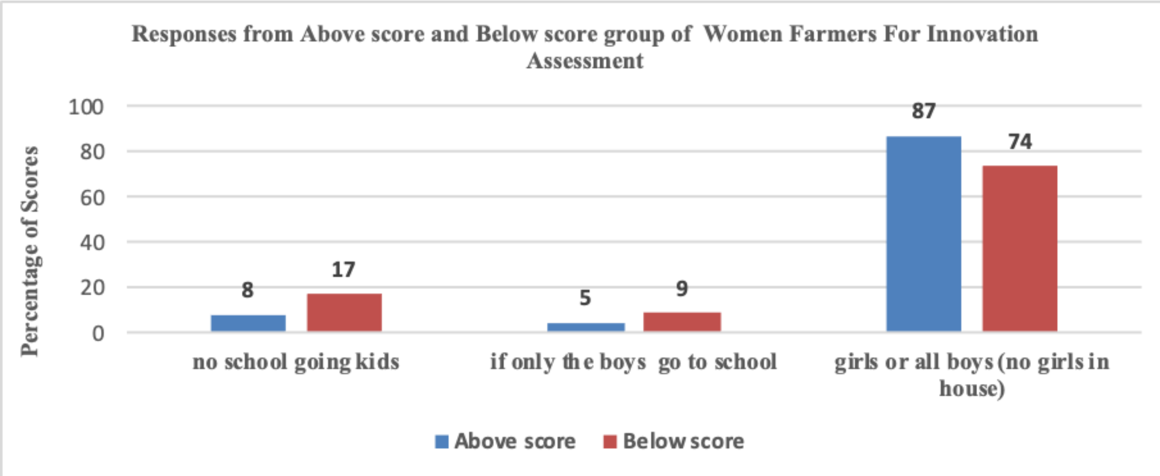


Figure 2-2: Proportion of respondents with school going kids (N=1607 women farmers)

What materials were used to build your home? (Question 2.1 of innovator survey)

The highest score in the innovator survey for this question was given if the respondent used more than 2 newer materials in building their homes. From the results, it can be concluded that the innovator group were scored higher (3 per cent) than the below-score cohort (1 per cent).

Table 2-3: Women Farmers' Responses Regarding Materials Used to Build Home.

Material Used	Score	Frequency & Percentage Representation	
		Above-score	Below-score
Traditional Materials or Tools	0	152 (81%)	1291 (91%)
1 Or 2 Newer Materials	1	30 (16%)	115 (8%)
More Than 2 Newer Materials	2	5 (3%)	14 (1%)
Total		**187**	**1420 (100%)**
Material Used	**Overall Average Score**	**Mean Above-score**	**Mean Below-score**
traditional materials/tools	21	27	15
1 or 2 newer materials	22	28	17
more than 2 newer materials	25	31	18

This question was useful for the research to select the best-bet innovators by identifying those who use none-conventional home building materials. The analysis shows that more of those in the above-score category have been using none-conventional materials to build their homes and are therefore more likely to try different ways of things as compared to those in the below-score category.

Do you have a mobile phone? (Question 2.2 in innovator survey)

The highest score was given if the respondent had a mobile phone. From the results in the table below, it can be seen that most innovators i.e. 76 per cent of those in the above-score category, have mobile phones while only 17 per cent of those who scored below the cut-off mark indicated that they had mobile phones. We can therefore expect a higher percentage of the innovator group who have access to a mobile phone and can easily communicate/access information as compared to the below-score cohort.

Table 2-4:Women Farmers' Responses Regarding Ownership of a Mobile Phone

Responses on Ownership of mobile phone	Score	Frequency & Percentage Representation	
		Above-score	Below-score
No	0	44 (24%)	1181 (24%)
Yes	2	143 (76%)	239 (17%)
Total		**187 (100%)**	**1420 (100%)**

This question enabled the research to select respondents who, given the rural context that they reside in, can be considered to be early adopters of technology and therefore more likely to possess innovation potential. They are more likely to have more exposure to various technologies and are more likely to easily communicate with others to exchange ideas compared to their peers.

If yes, how did you acquire your phone? (Question 2.2b of innovator survey)

The highest score was given if the respondents purchased the phones using their own source of funds/own means. From the results presented below, almost all of the respondents in the below-score category (92 per cent) did not purchase their own phones while a considerable number of innovators (57 per cent) purchased the phone using their own means. It should be noted that all the farmers assessed were more or less within the same income levels and therefore this factor did not impact their responses regarding self-purchase of mobile phones. We can therefore expect a higher percentage of the above-score "innovator" group to see added value and invest their income in useful technologies as compared to the below-score cohort.

Table 2-5: Women Farmers' Responses Regarding Sources of a Mobile Phone

Source of Phone	Score	Frequency	
		Above-score	**Below-score**
Gift/ Given by Someone	0	80 (43%)	1308 (92%)
Self-Purchase	2	107 (57%)	112 (8%)
Total		**187 (100%)**	**1420 (100%)**

If You Use A Phone, What Purpose Do You Use It For? (Question 2.3b)

The highest score was given depending on the response the farmers gave on what they have been using their mobile phones for. From the results presented, a large number of innovators/above-score group explained reasons that earned them higher scores during the screening of innovators as compared to the responses from those in the below-score category that showed 93 per cent were unable to explain the business purpose of using their phones.

Table 2-6: Responses Regarding Purpose of Mobile Phone Use in Business

Reason for Using Phone	Score	Frequency (%)	
		Above-score	**Below-score**
If Not Explained	0	76 (41%)	1319 (93%)
If Explained	1	111 (59%)	101 (7%)
Total		**187 (100%)**	**1420 (100%)**

59 per cent of the respondents in the above-score group i.e. those selected as innovators, were able to clearly explain the business purpose for which they use their mobile phones. These results indicate a higher likelihood for the selected "best-bet" innovator groups to have ideas on how to use technology for their business compared to those who scored below the innovator cut off mark. The above-score category is more likely to be exposed to improved inputs and farming practices and using these mobile phones, they can also get access to agricultural information provided through short-message (SMS) based systems in Malawi. Considering all the above findings, they would be the group with the higher likelihood of having innovative ideas.

Do you have a radio? (Question 2.4 of innovator survey)

The highest score was given if the respondent had a radio. Almost all above-score respondents i.e. those selected as innovators (82 per cent) have radios while only 34 per cent of the group of below-score respondents have radios. It can therefore be expected that information through radios is more likely to reach a significant number of best-bet innovators as compared to the respondents in the below-score category. This question identified respondents with access to a radio who are therefore more likely to be exposed to information/ideas as compared to those in the below-score category. This therefore places them in a higher probability of having more exposure and therefore higher likelihood to be innovative as compared to those who do not get as exposed to information.

Table 2-7: Women Farmers Responses Regarding Ownership of a Radio

Ownership of Radio	Score	Frequency (%)	
		Above-score	**Below-score**
No	0	33 (18%)	941 (66%)
Yes	1	154 (82%)	479 (34%)
Total		**187 (100%)**	**1420 (100%)**

If, Yes, What Radio Station Do You Usually Listen To? (Question 2.4b of innovator survey)

The highest score was given if the most listened radio station promoted farming either through market promotion or promotion of new varieties, among other beneficial information. From the results in the table above, 41 per cent of the respondents who mentioned agriculture-related radio stations were in the above-score category while only 11 per cent of the below-score category indicated these same radio stations. More of those selected in the above-score category indicated that they choose to listen to agriculture-related radio stations to improve their on-farm productivity and generate more income. The high scorers are therefore more likely to be more entrepreneurial and are therefore exposed to income-generating/other productive ideas as compared to those in the below-score category which would translate to a higher chance of innovative thinking given the same enabling environment.

Table 2-8: Women Farmers Responses Regarding Radio Stations Most Listened To.

Type of Radio Stations Listened to	Score	Frequency (%)	
		Above-score	**Below-score**
If Not Explained	0	111 (59%)	1261 (89%)
If Explained	1	76 (41%)	159 (11%)
Total		**187 (100%)**	**1420 (100%)**

Do You Use Irrigation Methods in The Dry Season? (Question 3.8 of innovator survey)

The highest score was given if the household indicated that they practice irrigation during the dry season. From the results below, it can be concluded that more innovators i.e. above score category (67 per cent practice irrigation as compared to those in the below-score cohort (42 per cent). We can therefore expect a higher proportion of farmers from the group of innovators (above-score category) involved in crop production during the dry season and therefore being innovative to find alternative means to have year-around production rather than relying only on the unimodal rain patterns in Malawi.

Table 2-9: Women Farmers Responses Regarding Use of Irrigation Practices.

	Score	Frequency	
Use of Irrigation Practices		**Above-score**	**Below-score**
No	0	62 (33%)	816 (58%)
Yes	2	125 (67%)	603 (42%)
Total		**187 (100%)**	**1419** (100)

This can be further interpreted to mean that those in the above-score category are more open to technologies that will boost their productivity and are willing to invest some of their income with the aim of getting a higher return on their investment in irrigation as opposed to the below-score category that relies only on the unimodal rain season in Malawi.

Have You Ever made or improved Your Tools for Farming? (Question 3.9 of innovator survey)

The best score was given if the farmer indicated that they have either made or improved their own tools for farming. 56 per cent of the respondents in the above-score category indicated that they have made or repaired their tools in the past compared to only 15 per cent of the respondents in the below-score category. We can therefore conclude that farm tools are more likely going to be domestically improved by the respondents in the above-score category/innovators as compared to the none-innovators.

Table 2-10: Frequencies & Percentages of Scores Based on The Use of Phone in Business.

Tool Making/ Tool Improvement Capability	**Score**	**Frequency**	
		Above-score	**Below-score**
No	0	82 (44%)	1209 (85%)
Yes	2	105 (56%)	211 (15%)
Total		**187 (100%)**	**1420 (100%)**

This question was validated for the innovation assessment as it enabled the research to identify the respondents with a higher likelihood of conceptualizing and making new tools or repairing existing tools. There were a higher number of respondents in the above-score category that indicated that they have experience with either making or improving tools. Therefore, they would also be the group with better tools and therefore more rewarding and positive farming experience as compared to those in the below-score category who relied on others to make or repair their tools.

Do you have access to Draught Animals? (Question 3.10 of innovator survey)

The best score was given if the farmer has access to draught animals. From the results, more of the respondents in the above-score category (42 per cent) indicated that they have access to draught animals as compared to only 13 per cent of the respondents in the below-score category who indicated the same.

Table 2-11: Women Farmers' Responses Regarding Access to Draught Animals

Women Farmers' Responses Regarding Their Access to Draught Animals			
	Score	**Frequency (%)**	
		Above-score	**Below-score**
No	0	108 (58%)	1240 (87%)
Yes	2	79 (42%)	180 (13%)
Total		**187 (100%)**	**1420 (100%)**

These findings indicate that while the below-score category relies solely on human labour, the respondents in the above-score category scored higher points and are considered better innovators as they have access to and use draught animals to reduce the burden and drudgery of labour intensive work such as tilling the land using a traditional hoe or transporting produce by hand. It should be noted that all the farmers selected do not own the draught animals but instead rent or do piece work in exchange for usage of the draught animals.

What Kind of Machines Do You Use in Your Farm? (Question 3.11 of innovator survey)

The highest score was given if the respondent indicated that they used mechanized machines on their farms. From the results, 14 per cent of the respondents in the above-score category indicated that they use mechanized farm machinery as compared to 5 per cent of the farmers in the below-score category who were categorized as none-innovators.

Table 2-12: scores based on the type of machines used in their farms

Type of Farm Machinery Used	**Score**	**Frequency**	
		Above-score	**Below-score**
By Hand (No Machines)	0	154 (82%)	1348 (95%)
Manual Machine or Animal Driven	1	7 (4%)	5 (0%)
Mechanized	2	26 (14%)	67 (5%)

This question was validated for the innovation assessment as more of those in the above-score category reported that they have access to and use mechanized farm machinery and are therefore more likely to have less intensive work and complete their farm operations in time as compared to those in the below-score category. These respondents in the above-score group are also more likely to be more open to testing new technologies and saving their time and energy for other tasks and therefore have higher probabilities of innovative thinking as compared to those in the below-score category of responses.

How Do You Transport & Market Your Farm Produce? (Question 3.12 of innovator survey)

The best score was given if the household reported that they use a personal car, minibus or motorcycle to transport their farm produce to the market. From the results, 12 per cent of the innovators i.e. those in the above-score category indicated that they use their personal car, minibuses or motorcycle to transport their farm produce to the market compared to only 3 per cent of the none-innovators i.e. those in the below-score category. Faster (modern) modes of transporting farm produce to the market are therefore more likely to be used by respondents with innovative capacity as compared to none-innovators. This is because those with faster transport options are more likely to be more efficient in their time management and are more organized. This may be interpreted further to indicate innovative capacity as they would also be better placed to conceptualize labour-saving tools as compared to those who are presently using traditional methods of transporting their produce.

Table 2-13: Scores Based on Types of Transport for Produce to Market

How Farmers Transport Farm Produce	Score	Frequency	
		Above-score	Below-score
On Foot	0	97 (52%)	1181 (2%)
Cart or Bicycle	1	68 (36%)	201 (14%)
Personal Car, Minibus, Motorcycle	2	22 (12%)	38 (3%)
Total		**187 (100%)**	**1420 (100%)**

This question enabled the research to identify those respondents who use none-conventional methods to transport their produce. Based on the responses and scoring, more of those in the above-score category have access to faster modes of transportation like bikes, carts motorcycles or cars (36 per cent and per cent and can easily and quickly transport their farm produce to the market as compared to those in the below-score category. This also indicates a higher likelihood for the above-score category to be exposed to more technologies and can therefore participate actively in the identification and development of tailor-made technologies.

Where do you sell the produce from your farm? (Question 3.13 of innovator survey)

The highest score was given if the farmer sells their farm produce outside their location (village or town). From the results below, 38 per cent of the above-category respondents i.e. the best-bet rural innovators, sell their farm produce outside their immediate locations as compared to 30 per cent of the below-score respondents (none-innovators).

Table 2-14: Women Farmers' Responses Regarding Where They Market Farm Produce

Markets for Farmers' produce	Score	Frequency	
		Above-score	**Below-score**
Within Village	0	5 (3%)	72 (5%)
Admarc	1	111 (59%)	924 (65%)
Outside Village, Same Town	1.5	59 (32%)	366 (26%)
Outside Town	2	12 (6%)	58 (4%)
Total		**187 (100%)**	**1420 (100%)**

Have you tried to sell your produce in a different way/add value? (question 3.14 of innovator survey)

The highest score was given if the respondent indicated that they add value to their products and provided a description of how value was added to their produce. The results illustrate that a 61 per cent of the respondents in the above-score category (those categorized as innovators), are involved in value addition of their farm produce before they sell them as compared to the respondents in the below-score category i.e. those categorized as the none-innovators (21 per cent).

Table 2-15: Women Farmers' Responses Regarding Value Addition or Unique Marketing

Value Addition or Unique Marketing	Score	Frequency	
		Above-score	**Below-score**
No	0	71 (38%)	1099 (77%)
Yes, But Not Described	1	1 (1%)	18 (1%)
Yes, And Described	2	115 (61%)	303 (21%)
Total		**187 (100%)**	**1420 (100%)**

This question was validated for the assessment of respondents' innovation capacity because the research was able to successfully identify respondents who indicated that they engaged in value addition or use unique selling techniques. Those respondents doing value addition and applying unique sales techniques therefore scored higher on the innovator score as they demonstrated the innovative capacity in adding value as this indicates that they see the added value in the form of added income generation. This kind of business-minded approach is a good indicator of innovator capacity in the development of labour-saving technologies.

Please Describe How You Added Value to Your Produce? (Question 3.14b of innovator survey)

The highest score was given if the respondent indicated that they previously carried out new ways of doing things and provided a description. The results indicate that a larger number of above-score respondents i.e. innovators (73 per cent), described how they engage in value addition of their farm produce in a none-conventional way compared to the below-score category i.e. none-innovators (35 per cent).

Table 2-16: Women Farmers' Responses Regarding Unique Value addition

Types of Value Addition mentioned By Women farmers	Score	Frequency	
		Above-score	Below-score
No	0	51(27%)	904(64%)
Yes, But Not Described	1	0(0%)	15(1%)
Yes, And Described	2	136(73%)	501(35%)
Total		**187(100%)**	**1420(100%)**

This question enabled the research to accurately capture the difference between the best-bet innovators and the none-innovators regarding value addition. Based on these results, more of those in the above-score category described their value addition approaches and are hence more likely to bring new ideas in technology development as compared to those in the below-score category. These diverse approaches of doing things would potentially bring added value to the conceptualization and design of labour-saving technologies.

Have you ever thought of new, different or better ways to do something, for example, for harvesting, weeding or processing your farm produce? (Question 3.15 of innovator survey)

The best score was given if the farmer described how and what that they have ever thought of doing in a new, different or better to manage their farm-related tasks. According to the results, a majority of the above-score respondents classified as innovators i.e. 73 per cent described their ideas well and were able to demonstrate what they thought of doing in a new, different or better way.

Table 2-17: Responses Regarding New Ways of Handling Farming Tasks.

New Ways of Handling Farming Tasks	Score	Frequency	
		Above-score	Below-score
No	0	51 (27%)	904 (64%)
Yes, But Not Described	1	0 (0%)	15 (1%)

Yes, And Described	2	136 (73%)	501 (35%)
Total		**187 (100%)**	**1420 (100%)**

This question enabled the research to accurately capture the difference between the best-bet innovators and the none-innovators regarding new idea generation. Therefore, based on the scores, there is a higher likelihood of acquiring inputs for technology designs from those in the above-score category as they have thought of doing things differently and have higher changes of being able to express their ideas clearly to demonstrate the benefits of these innovative approaches. The ability of users to describe their needs and ideas is important for the conceptualization and design of labour-saving technologies that are tailored to the end-user and tested by the end-user as these end-users would be able to communicate the changes they require/prefer in the technologies under development rather than assuming the developer is the expert and source of all knowledge. Those that did not describe any new ways of doing things would not be expected to share any new insights/inputs during a technology development process as they typically would just continue doing "business as usual" rather than attempting new improved ways of tackling their day to day challenges.

Were You Able to Carry Out Your New Idea to Manage your Farm-Related Tasks? (Question 3.16 of innovator survey)

The highest score was given if the farmer was able to carry out their new idea from question 3.15 above. From the results, higher numbers (29 per cent) of the innovators were able to carry out their new ideas while the none-innovators reported only 3 per cent.

Table 2-18: Women Farmers Responses Regarding Testing Out New Ideas.

Responses Regarding Testing Out New Ideas	**Score**	**Frequency**	
		Above-score	**Below-score**
No	0	133 (1%)	1377 (71%)
Yes	2	54 (29%)	43 (3%)
Total		**187 (100%)**	**1420 (100%)**

This question enabled the research to identify and select the respondents who have tested out their ideas as they demonstrated a higher possibility for developing and testing useful ideas for their farming operations. This demonstrated higher risk-taking capacity for the respondents above the innovator cut-off score who were labelled "best-bet innovators" as compared to the below-score category.

If yes, what was the outcome? (Question 3.16b of innovator survey)

The highest score was given if the outcome of the innovation in 3.15 above was positive. According to results, it can be concluded that more positive results were observed from the above-score category i.e. the innovators (22 per cent), as compared to only 1 per cent of the below-score category referred to as the none-innovators.

Table 2-19: Scores based on the outcomes of Farmers' new ideas

Positive Outcome of New Idea Testing	Score	Frequency	
		Above-score	Below-score
No	0	146 (78%)	1401 (99%)
Yes	2	41 (22%)	19 (1%)
Total		**187 (100%)**	**1420 (100%)**

Using this question, the research was able to identify and select the respondents who have tried testing out their ideas successfully. The results indicate that more of those in the above-score category had a higher rate of positive outcomes when trying their new ideas indicating higher likelihood of coming up with feasible ideas for labour-saving technologies as compared to those in the below-score category. In addition, their willingness to take risks and test their ideas indicates a willingness to try something new and unconventional, which is a good indicator of a best-bet innovator. The selection based on successful outcomes was based on reasoning that those who did in fact have positive outcomes had spent more time in conceptualizing their ideas to think of and address any potential bottlenecks that would otherwise hamper the innovative idea from coming to fruition.

Do you have any other business other than farming? (Question 4.1 of innovator survey)

The highest was given if the household had another business apart from farming. From the results, a majority of the innovators (78 per cent) indicated that they had other businesses apart from farming as compared to the other group of below-score respondents.

Table 2-20: Women Farmers Engagement in Other Businesses from Farming

Other Businesses from Farming	Score	Frequency	
		Above-score	Below-score
No	0	42 (22%)	842 (59%)
Yes	1	145 (78%)	578 (41%)
Total		**187 (100%)**	**1420 (100%)**

This question enabled the research to identify the respondents in the above-score category who demonstrated a higher capacity to diversify their income sources (businesses) than none-innovators. The results demonstrated that more of those in the above-score category have been involved in other businesses apart from farming and are therefore more likely to diversify their income-generating activities from only farming to other types of businesses , as compared to those in the below-score category. They are therefore more willing to take risks by investing in business outside of farming. This willingness to take risks and invest their money indicates that they are more likely to innovate and try out new innovations as compared to those in the below-score category.

If yes, what type of business do you run?(Question 4.1b of innovator survey)

The best score was granted if the farmer was running a business that was not commonly practiced by others in the same community. From the results, almost all farmers (80 per cent innovators and 95 per cent none-innovators) in the study area run common businesses although a higher percentage of respondents were in the below-score category. However, with respect to the uncommon businesses, the above-score/innovator group scored higher (20 per cent) than the below-score/none-innovators (5 per cent).

Table 2-21: Scores Based on Type of Business They Are Engaged In.

Business They Are Engaged In	Score	Frequency	
		Above-score	Below-score
Common Business	0	149 (80%)	1346 (95%)
Uncommon Business	1	38 (20%)	74 (5%)
Total		**187 (100%)**	**1420 (100%)**

The higher scores were from those in the above-score category who are therefore more likely to venture into new unique businesses as compared to those in the below-score category. This question enabled the research to identify the early adopters of new business ideas who by doing so demonstrate their willingness to explore new ideas and take risks. These characteristics demonstrate persons with an ability to innovate or conceptualize new ideas. Some of these unique/uncommon businesses includes ICT based movie shops/ “theatres”, delivery of services to farmer’s homes as customer after sales service, buying and selling of produce in addition to farming where more income is generated, selling in markets outside their immediate community, among others.

Who is usually first at trying out new initiatives in your community? (Question 6.3 of innovator survey)

To determine whether a farmer within the innovator group (187) was already locally recognized by other peer-farmers as an innovator, the survey respondents were asked to identify who in their community is usually first at trying out new initiatives (Q6.3). From the 1607 farmers, 45 provided a name of an innovator where the same name was sometimes proposed by multiple respondents. 21 names out of the 187 selected farmers who were identified as innovators were also recognized as the first people in their community who are early at trying out new initiatives (i.e. early adopters). This indicates that the innovator screening criteria was overall very successful in selecting the early adopters/innovators.

Do other women ever come to you for advice or try to copy what you do, for example, in your farm or other business? (Question 6.4 of innovator survey)

The highest score was given to farmers if they said that other farmers come to seek advice from them. From the results, a majority of above-score category (innovators) respondents (86 per cent) indicated that they have been approached by other farmers for advice as compared to only 33 per cent of the responses from the below-score category (none-innovators). .

Table 2-22: Farmers' scores: Do people come to seek advice from them

Whether Others Come to Them for Advice	**Score**	**Frequency**	
		Above-score	**Below-score**
No	0	26 (14%)	952 (67%)
Yes	1	161 (86%)	468 (33%)
Total		**187 (100%)**	**1420 (100%)**

This question enabled the research to accurately capture and select the respondents who have had other farmers approach them for advice in the past and who are considered reliable and trustworthy. Compared to those in the below-score category, almost twice the number of respondents in the above-score category indicated that some farmers came to seek advice from them and are therefore more likely to have better ideas. They would therefore be the group with the higher likelihood of having ideas for conceptualizing labour-saving tools that can reduce the drudgery for their own farm tasks as compared to the farmers who were not selected to participate.

Please identify women in your community who are best at business. (Question 6.5 of innovator survey)

Of the 187 farmers who were selected as best-bet innovators based on the innovator survey scores, 34 (18.18 per cent) were identified as best business women by their peers. This question was therefore instrumental in identifying innovators as some of the identified respondents were also verified by their peers.

Do you know anyone who employs others in other business except farming? (Question 6.6 of innovator survey)

Among the group of those who employ others in different businesses other than farming, 2 were from the above-score/innovator group of the women farmers.

Who are the largest producers and what do they produce? (Question 6.7 of innovator survey)

7 of the respondents in the above-score category of women farmers were identified to be among the biggest producers of commodities in their communities.

2.3.2 Distribution of Scoring for Innovator Screening

The research liaised with a range of experts on grassroots innovation (Gupta et al., 2003, Hossain, 2016) (Wettasinha et al., Undated, Douthwaite et al., 2002) during the process of developing an innovator screening tool to distinguish between high innovator scoring farmers and low innovator scoring farmers. To identify women smallholder innovators in the targeted sites, an innovator assessment questionnaire survey was designed consisting of fifty-five questions, out of which 39 questions were actually scored to assess for innovation potential. The survey included questions capturing baseline data as well as questions that aimed to segment the audience by assessing personal and financial profiles, early adoption of technology, entrepreneurship potential and farming practices (Appendix 2) which fall among characteristics of innovators as described by (Poirier et al., 2017, Swim, 2017). As (Smith and Findeis, 2013) explains about segmentation of the audience, it would in this case help to identify the best-bet innovators from the group of the female farmers in Malawi with highest potential to conceptualize labor-saving technologies tailored to the demands of their cropping systems as compared to their fellow smallholder farmers. (Patterson and Zibarras, 2017) called the them trait-based measure of creativity and innovation potential. (Patterson and Zibarras, 2017)'s results suggested that openness to experience is positively related to creativity and innovation and the same observation was supported by (Fursov et al., 2017).

The initial questionnaire comprised of six sections that were designed to assess the respondent's personal potential for early adoption of technology, entrepreneurship potential, and knowledge of other smallholder farmers who demonstrated innovative thinking and pioneered activities accordingly. The questionnaire also captured the respondents' household baseline data on assets, access to credit and financial services. The remaining 16 questions were used to collect demographic information and were not relevant for capturing innovation potential but were useful background data that was used in the research. The criteria used to differentiate innovators from those with less innovative capabilities were:

a. *Use of non-conventional building materials,*
b. *Use of mobile phones to access agricultural information*
c. *Likelihood of educating the girl child to level access to education*
d. *Use of non-conventional planting methods.*

The distribution of the innovator scores for the 1607 farmers relative to the innovator farmers that were selected as the best-bet innovators is provided in the table below. The distribution of the innovation scores was not skewed indicating a good resolving power of the innovation scoring system. Based on an innovation score cut-off, 187 farmers were identified where 65 people scored between 36 per cent and 39 per cent, 116 people scored between 40 per cent and 59 per cent and 6 people scored between 60 per cent and 65 per cent, while 1 person scored 75 per cent. The summary table below provides an overview of the innovator screening criteria & scoring system for identification of best-bet innovators.

Table 2-23*: Breakdown of Questionnaire Showing Distribution of Scores*

Questionnaire Sections	**Number of Questions**	**Scoring Weight (Points)**	**Scoring Weight (%)**
Household characteristics	1	2	4%
Early Adoption of Technology	8	10	18%
Farming Methods	6	8	15%
Access to Assets & Mechanization	6	12	22%
Value Addition	8	10	18%
Entrepreneurship Potential	6	7	13%
Savings Potential	2	3	5%
Community Involvement	2	3	5%
Mean (for the above-score)		**27.03**	**49%**
Mean (for the below-score)		**14.84**	**27%**
Total	**39**	**26128.50**	**100%**

The sections that contributed highly in the scoring included the sections dealing with access to mechanization (22 per cent), followed by early adoption to technology and value addition (18 per cent).

Farming methods and entrepreneurship ability sections also contributed highly (15 per cent and 13 per cent respectively), but financial status and community, community involvement and the household characteristics sections had low contribution to the scoring and screening of the innovators. The above-score group scored highly as shown by their mean score and percentages (27.03 and 49 per cent) but the below-score group scored low (14.82 and 27 per cent). Innovators were therefore selected from the group of the highly scored female farmers. The study investigated areas that are already in practice by the farmers so that its findings may be able to improve on the existing knowledge and skills hence economic development as recommended by (Naylor, 1999).

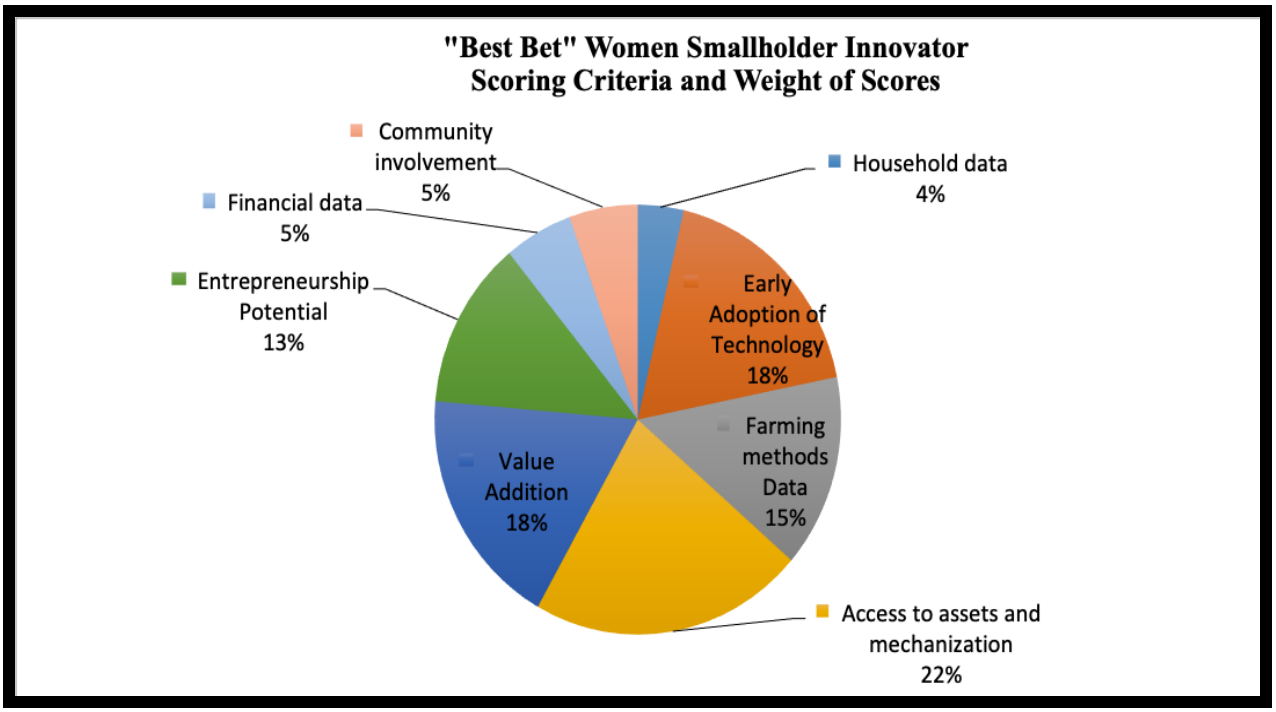


Figure 2-3: Distribution of Innovator Scores based on survey sections (N=1607).

2.4. Discussions and Conclusions

2.4.1 Evidence That Selected Women Farmers Are the Top Ranked Innovators

The findings presented above demonstrate that the research confirmed the possibility to screen women smallholder farmers and select those with the potential to innovate. The scoring methodology used ensured that those selected were the top scorers who scored above the cut off score (described in section 2.3.3) who have the best chances of innovating based on their responses to the innovator survey. These groups of women smallholder farmers were classified as "Best-Bet Innovators" the throughout the research as described by (Tambo and Wünscher, 2015, Chambers and Jiggins, 1987) since there was no counter-factual control group that we were comparing them to. However, the farmers demonstrated that, given an enabling creative environment, the women innovator groups were able to answer the screening questions and understood how they were selected and why. They also took the time to ask several questions to better understand their role in the research and ensured that they had an accurate understanding of innovation and innovation assessment in their rural context.

2.4.2 Criteria for Innovator Identification in Rural Contexts

While a range of criteria were used to identify the best-bet innovators (Tambo and Wünscher, 2015), some of the questions were more instrumental in identifying the high scoring respondents as the difference in the scores of the high scorers and low scorers was statistically significant. Generally, the questions that related to communication and access to information were instrumental in assessing the women farmers who had the capacity to easily communicate with others and access information compared to the group of non-innovators. The respondents' willingness to spend funds for an ICT tools that improved their access to communication and information demonstrated potential for innovation as they can be considered early adopters of technology and risk takers. Respondents who demonstrated a higher capacity for innovative thinking were also identified using questions on what ICT tools were used for with regards to their farming activities. These types of questions also enabled the research to identify those who are more likely to be exposed to ideas and information as compared to those below the innovator cut off score (Baliwada et al., 2017, Fursov et al., 2017). We can therefore expect that a higher percentage of the innovator group accesses more information using ICT to promote their farming as business and would therefore demonstrate more capacity for innovation and doing things differently.

Questions related to farm-related activities were also instrumental in identifying the innovators. Farmers who get their main income from on-farm activities can gain from improved agricultural technologies compared to the landless rural households who focus on the off-farm activities (Dethier and Effenberger, 2012). They tended to do things differently on their farms and with their farm produce i.e. their methods, modes of transport, market selection among others.

Responses from the innovators also indicated a higher likelihood for the innovator groups to indulge in winter crop production as compared to their none-innovator counterparts. This further indicates a higher likelihood of these innovator groups being involved in income generating activities and having access to the added exposure of their mobility to markets and other villages and towns.

When asked whether they have ever improved/fixed a farming tool, the highest score was given if the farmer indicated that they have either made or improved their own tools for farming. From the results, respondents from the group of innovators (56 per cent) showed a higher percentage of scores than the non-innovators below the cut off score (15 per cent). This question was very useful in assessing innovation potential as we can therefore conclude that farm tools are more likely going to be improved by the women farmers in the innovator groups as compared to the non-innovators who scored below the cut off. Please refer to the results section for details of each of the questions that were used to assess the innovation potential of the 1607 farmer respondents.

2.4.3 Effects of "Innovator" Classification on Mind-set and Behavior

The process of going through the innovation screening process was very engaging for the women smallholder farmers who had previously not been involved in an innovation research and design initiatives. According to the women smallholder farmers' feedback, this active engagement was very empowering for them. Some participants indicated that they had never been to school but through this project screening exercise, they were more confident as they felt as though they had "passed" a test. This motivated them to contribute to the conceptualization and testing discussions rather than expecting the researchers to produce results as the "experts". As (Njuki et al., 2014) states "Whether or not the suggested farm machinery and agricultural practices are feasible for long-term agricultural development, their contribution to increasing women's self-confidence and self-esteem is a key factor in women's empowerment and gender equality".

2.4.4 Evidence that selected Innovators are the Best- Bet Innovators

To conclusively demonstrate that the 187 innovators identified are indeed the best-bet innovators from the 1607 screened, the research would have required that we conducted a randomized control treatment type design for the overall PhD study where the 187 selected innovators would be compared to a matched (similarly structured) sample of 187 farmers randomly sampled from the overall 1607 farmers surveyed. In principle, such a design would have determined whether selecting innovators was more likely to result in improved outcomes rather than just sampling 187 farmers randomly i.e. answering the question as to whether innovators are any better than an average group. However, due to major funding inconsistencies and difficulties, a multi-annual RCT type design could not be conducted in this PhD research and hence the question cannot be answered in this project as to whether the 187 innovators identified are indeed the innovators from the 1607 screened. This is the rationale for the use of the "best-bet" qualifier in the description of the innovator cohort selected for the subsequent stages of the research.

Overall, the research conducted in this 2nd thesis chapter took the first crucial step in identifying the "best-bet" women innovator groups to be engaged the agri-tools PRTD process. the research was cognizant of the difficulties in identifying innovators in any setting, and especially in poor rural settings where innovation amongst women farmers may not be expected or encouraged. The research aimed to find the "best-bet" innovators among the women farmers and all interested women farmers were all exposed to the idea of innovation and the various definitions in agriculture to enhance their understanding before the innovator screening was conducted. The women innovator groups responded well to the fact that the researchers were investigating their ability to contribute value-adding inputs to the development of agri-tools and machines for their benefit. This encouraged the farmers who were selected as best-bet innovators as from the feedback given to the research team, the process of being involved in the innovator assessment gave the women smallholder farmers the positive feeling of being selected because they were considered more creative and capable of innovating or adapting technologies to suit their own needs.

While the typical approach in Malawi does not usually involve women in the tool innovation and design process, this research explored unique approaches to identify best-bet innovators in the rural settings of Malawi whose capacities to identify their labour constraints and co-design labour saving technologies would be assessed. The next chapter provides a summary of the research activities conducted after the innovator screening exercise was conducted and focuses on the in-country setting for development of labour-saving technologies in Malawi.

3. CHAPTER 3: LABOUR, TECHNOLOGY & RESOURCE CONSTRAINTS

3.1. Research Objectives

The objective for this topic was to:

- *map the key constraints that present major challenges for women smallholder farmers. Having identified the "best-bet" innovators in Chapter 2, this chapter aimed to assess the labor, technology, and resource constraints that women farmers and their households have in Malawi. The expectation was that the lessons learned from this intensive field work would highlight the benefits of working with women smallholder farmers to identify the best use of their resources to design innovations that can enable them to be more productive, generate more income and improve their livelihoods (SELCO, 2017, Vereijken, 1999).*

- *The second research objective assessed the causal factors leading to low uptake of improved agri-technologies and a lack of sustainable adoption of improved tools and mechanized equipment.*

As part of the initial review, there were indications that there were other smallholder farmer-targeting technologies in the Malawian markets that smallholder farmers had heard of but never seen. This in itself presents a challenge to them as they have limited to no knowledge of any new or improved agricultural technology that has been introduced into the market and whether that technology can be of benefit to them. The research results would enable the research to better equip the smallholder farmers with the technical knowledge of new and improved technologies and how their efficient adoption, use and maintenance can benefit farming households economically and socially in a sustainable manner.

3.2. Research Methodology

3.2.1 Identification of Household Labour Distribution

To be able to understand and design the right labour-saving innovations, the women innovator groups needed to be engaged through a participatory approach where they can offer their inputs and value adding contributions in an inclusive setting (O'Neill, Chambers, 1994 , Cavestro, 2003). This would be a comfortable, enabling environment where they would be able to share as a group and individually, in a well thought out and concise manner.

This chapter summarizes the research activities that engaged women smallholder farmers in Malawi to capture how they currently perceive their workloads and what the peak labour demand periods are that are considered to be a burden/labour intensive. The research explored participatory rural appraisal (PRA) tools as applied by other researchers (Chambers, 1994 , Cavestro, 2003) to map out labour roles in the household as well as the breakdown of daily activities by peak and off-peak periods in the days and months in the farming cycle.

Activity Clocks: The research used this tool to identify the daily workloads and labour requirements for women smallholder farmers and their households. Each farmer in the 16 innovator groups provided a detailed breakdown of the daily activities and prepared a 24-hour activity clock for themselves and their spouses, if applicable. The spousal component was completed by the women farmers with their spouses in their homes, which allowed for the conversation of labour distribution to be initiated within the household. This ensured the spouses opinions and contributions were also incorporated indirectly.

Key Questions Asked During Exercise: The facilitator used the following guiding questions during the activity clock focus group exercise:

i. *For each person, how is his or her time divided?*
ii. *Who has the heaviest workload and why? What task are they responsible for?*
iii. *Who has time for rest and leisure?*
iv. *Where do women spend most of their time?*
v. *Where do men spend most of their time?*
vi. *What is the difference between the women's and the men's clocks?*

To ensure accuracy of data recorded during each focus group exercise, the facilitator and note taker ensured the availability of flip charts, marker pens, tape, pencils, ruler, erasers, and pieces of paper. Each Focus group was given the same instructions for the activity clock exercise:

i. *Participants were asked to draw a circle and divide the circle into "pies" to represent each of their daily activities.*
ii. *The participants were then engaged to highlight how much time they spend on each of the activities they indicated in # 1 above.*
iii. *They were then asked to note the labour requirement for each activity mentioned above and how labour demanding the task was.*

iv. *Participants were asked to draw clocks for the two farming seasons i.e. the cultivation and post-harvest season.*

v. *When each participant had completed their activity clocks, the participants were asked to verbally describe their daily clocks at which point the facilitator asked questions about any unclear data collected.*

vi. *Activities that are carried out at the same time (such as child care and cooking) were noted in the same spaces/pies.*

The participants in each innovator group drew their activity clocks by season as well as those for their spouses, which were done in a participatory manner with their spouses at home. This enabled the research to have a gender-inclusive approach even where resources did not permit as the women participants and their spouses worked together to draw their daily clocks at home. The research then compared the clocks to analyze any discordance in the gender roles regarding household labour distribution. Refer to the appendix section to review the template developed to capture the 24-hr recall of work done.

3.2.2 Identification of Peak Labour Tasks and Associated Tools

Once the typical tasks for the household and farming activities from the activity clock exercises were identified, the research carried out various sessions using PRA tools to identify the various farming tasks highlighting those that women farmers classified as labour intensive. Seasonal calendar exercises were conducted where tasks were divided by time of year, specifically the cultivation and post-harvest seasons. The associated labour requirements and tools used for each activity were also indicated in the seasonal calendars.

Focus Group Discussions (FGDs) Regarding the Seasonal Calendar: This tool was used to identify the nature of the farming cycle, crops grown, tools used, labour requirements, as well as food, income and time availability among women smallholder farmers and their households. Each innovator group discussed the farming activities completed and prepared their annual calendar.

*Key Questions Asked During Exercise***:** The facilitator used the following guiding questions during the seasonal calendar exercise:

i. *What is the farming cycle (highlighting all activities they are involved in)?*

ii. *What tools/machines do women smallholder farmers use for each identified farming activity?*
iii. *What is the energy & labour requirements for tools and machines used throughout the year?*
iv. *What is the cropping calendar and what tasks are associated with each crop?*
v. *When are the optimum times in the year to engage in various activities?*
vi. *When are the school days? When are children expected to work in the farms and household?*
vii. *During which periods do farmers experience high and low food availability?*
viii. *During which periods do farmers have more disposable income?*

To ensure accuracy of data recorded during each focus group exercise, the facilitator and note taker ensured the availability of flip charts, marker pens, tape, pencils, ruler, erasers, and pieces of paper.

Each Focus group was given the same instructions to complete seasonal calendar tables below:

i. *Use scoring of up to 20 (the higher the score, the more value in that month)*
ii. *Participants were asked to indicate the farming cycle and tasks throughout the year*
iii. *Women farmers the mentioned the tools used for each of the farming cycle activities mentioned.*
iv. *Each group highlighted the months with the most rainfall and those with the least rainfall.*
v. *Each group indicated the months with the most income and those with the least income, highlighting when they purchased tools and inputs i.e. months with disposable income.*
vi. *Each group indicated the months with the most food availability and those where they experienced food shortages.*
vii. *Women farmers also noted when their children were off from school and available to help as well as when community cultural days were observed.*

The groups ranked the rainfall distribution in their regions from 0 to 20, indicated the tools used for their farming tasks and marked the months where the holidays, cultural and school days tool place. They also identified the food availability distributions in the year and indicated during with months they had any extra income than the typical months. All the above data was captured to have a holistic view of the women farmer’s context that would be taken into consideration during the research period. Refer to the appendix section to review the seasonal calendar template developed.

Smallholder farmers were also engaged to consider what they would do during any of the months where they had any extra time and income and were encouraged to highlight income-generating ideas for boosting their on-farm labour productivity. Refer to the appendix section to review the template developed to capture data on off-peak activities.

The groups also identified their cropping calendar (type of activities by type of crops e.g. Activities: B=Burning (weeds, vegetation); LP+ Land preparation (hoeing, ploughing); P=planting; W= weeding; H=harvesting; S= storage. Refer to the appendix section to review the template developed to capture data on the cropping calendar.

Each of the innovator groups completed their seasonal calendars based on the inputs of their participants. As the two sites have some variations in the rainfall patterns, type of crops grown and tools used, it was important to record the site-specific data to be able to identify any discordance between the two sites. The research was then compiled to be present the results based on the two surveyed regions of Malawi.

3.2.3 Roles and Responsibilities in the Household

During the FGDs, the research also collected data on how labour is distributed in the households that were represented in the innovator groups. Each women's innovator group was asked to indicate what on-farm tasks are carried out during the farming cycle as well as livestock care and general household and child care activities. The participants were then asked to specify who in the household was responsible for the tasks identified for their specific household and what the division of labour was i.e. who did most of the work related to a particular item and who else assisted. The labour distribution was divided and a table was prepared for each group to fill in based on the women smallholder farmers' feedback. It was on the basis of this data collected that the labour distribution was measured for the members of the household as is presented in the results section.

3.2.4 Resource Mapping

Through the research activities, the facilitator aimed to engage the women smallholder innovator groups to think about and map out their community's physical, social, economic and human resources. The research outputs for this would produce a resource map assessment and risk assessment for the future potential local production of agricultural tools in Malawi described in later chapters.

Resource Mapping: To identify the human, natural and other resources in the community, each innovator group was engaged in FGDs to map out, identify and estimate the value of resources available in the community.

Key Questions asked during the resource mapping exercise: The facilitator used the following guiding questions during the resource mapping exercise:

i. *What resources and skills are available from members of the community? Examples of these are: knowledge, labour and expertise (informal or formal) such as teachers, extension workers, medical professionals, financial service providers and others.*
ii. *What resources are found naturally occurring in the environment? These include vegetation, water sources, land, animals, forests, etc. (Where do people collect water and firewood?)*
iii. *What do members of the community have access to in terms of infrastructure and services? (Banks, schools, roads, irrigation schemes, transport systems, tool providers, and others.)*
iv. *What resources are available from their social network? (Local culture and traditions, village leadership structure, influential leaders and resource people, family and friends and others.)*
v. *Does everyone (men and women) have equal access to land and amenities?*
vi. *How is land acquisition determined? Who are the decision makers in the community?*
vii. *What resources are abundant and what are scarce?*

FGDs were instrumental in successfully exploring who all the players in the groundnut, bean, soya bean, and maize supply chains are from the grassroots perspective before conducting the market review. The research engaged the women smallholder farmers to identify their agricultural tool retailers and producers and where they were located. They also mapped out where their extension service planning areas were located, the kind and frequency of services they were offered and who their extension service officers were. In addition, they also indicated whether they received any other kinds of support from local or international organizations. The data collected was useful for the research to identify what human resources/advisory services the women had access to in order to better capture their levels of exposure to information, particularly regarding agricultural technologies, which was instrumental in understanding their innovative potential.

Each focus group was given the same instructions to complete resource mapping activity:

i. *Participants were asked to first identify their drawing space and identify an object to represent their central landmark.*
ii. *The facilitator then asked for a volunteer to draw the boundaries of the villages.*
iii. *Women farmers identified their villages, farms, irrigation plots and water collection points. Once*

these points were mapped out, they also drew the main roads and foot paths used to walk to their farms, and water collection points.

iv. *Groups were also asked to map their markets and places of business and where their purchased or sold their produce, if applicable.*

v. *Retailers of agricultural tools and machines as well as tool producers were also mapped.*

vi. *The women smallholder farmers also mapped out the hospital, police, AEDOs and EPAs locations and the chief and village head locations. In addition, organizations that supported farmers were also identified and their locations mapped out.*

vii. *The innovator groups were encouraged to draw the resource maps on flip charts and indicate the compass directions. The researchers were careful and observed without interrupting the participants unless they stop drawing or got distracted.*

The facilitator interacted with the innovator groups to map out available resources as well as locations and availability of raw materials for agricultural tool production in Malawi. In addition, locations of local tool producers and bicycle repair people were also included in the mapping exercise. These would potentially be the labour force and source of spare parts and would be responsible for regular maintenance of the technologies co-designed with the innovator groups.

The research indicated the key symbols to be used by each group during the resource mapping exercise:

- *Major roads accessible by cars and oxcarts and indicate where they lead to*
- *Foot paths accessible to pedestrians and bicycles*
- *Buildings such religious institutions, police and schools, health posts,*
- *Agricultural extension planning areas and leadership units*
- *Farm areas and Irrigation plots*
- *Residential areas and indication of number of households per village*
- *Forested areas*
- *Communally used areas*

3.2.5 Assessment of Existing Tools Used for Labour Intensive Tasks

The research investigated the existing tools and machines that are available for women farmers and their households. Each innovator group was asked to bring the tools they currently use for the labour-intensive tasks they identified. Similar to other participatory research conducted (O'Neill, Chambers, 1994 , Cavestro, 2003); the researchers employed a step by step approach to the development of database of existing tools used. The women farmers measured specific dimensions for the tool handles and blades and used this as a starting point for the co-design process to test their potential to co-design labour-saving tools. They also identified purchase points for the tools and the locations of local tool producers.

3.2.6 Data Analysis Approaches

Microsoft Excel: Quantitative and qualitative data was collected during focus group discussions that were conducted in local languages. The note taker summarized all the discussions during the exercises described above an afterwards, the data was coded and entered into MS Excel for cleaning, analysis and presentation using tables and graphs.

SPSS: In addition to MS Excel, the research also incorporated the use of The Statistical Package for Social Scientists (SPSS) Package to calculate the mean comparison which involved Analysis of Variance (ANOVA) to compare daily average time allocation for different activities done by male and female farmers during dry and rainy seasons; mean scores for monthly income availability for farmers with respect to their location; mean scores for monthly household expenditure for farmers with respect to their location and mean scores for monthly household food availability for farmers with respect to their location. The data was analysed at 95 per cent level of significance and significant differences were determined by a P.value of <0.05. Multiple response analysis involving cross-tabulations lead to the descriptive analysis of the tasks based on who typically is responsible for household task/activity.

Figure 3.3.6 Focus group discussions in the study areas, photo taken by Zewdy Gebremedhin

3.3. Results

3.3.1 Distribution of Activities Among Men and Women: Activity Clock Outputs

Based on the 24-hour recollection of activities exercise conducted for each group of innovators, the average time taken for men to complete on-farm tasks was less than the tasks and time taken for women. Women had 11 tasks to complete compared to eight for men in the post-harvest season. In comparison, during the cultivation season, men had seven tasks compared to nine for women. Women were responsible for all in-household tasks.

The results in the figures below demonstrate that women in both rainy and dry seasons are involved in almost all household activities except construction and irrigation and spend little time on sleep and rest during most times of the day as compared to male farmers. During both dry and wet seasons, women assessed spend more time doing farm work than men. Men spend more time in various income generating activities than women. On average, men spend 12.5 hours resting while females spend only eight hours and these findings are supported by (Blackden and Wodon, 2006, Wodon and Beegle, 2006) who observed that there are marked differences in how much and on which tasks men and women spend their time.

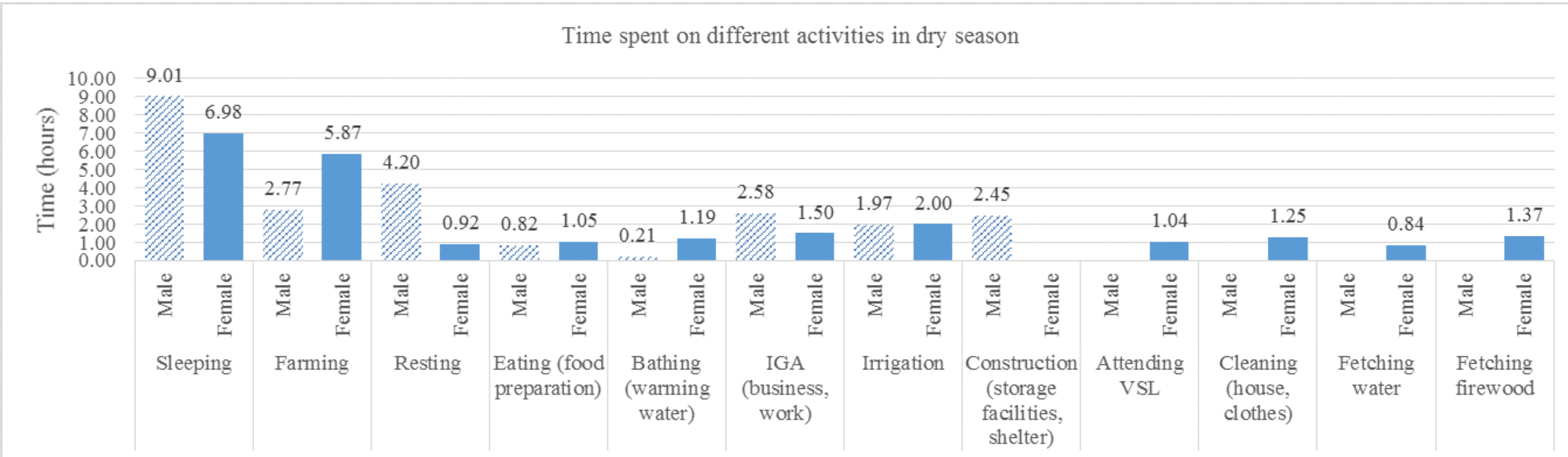


Figure 3-1: Average time spent on activities during the dry season. (n=187s).

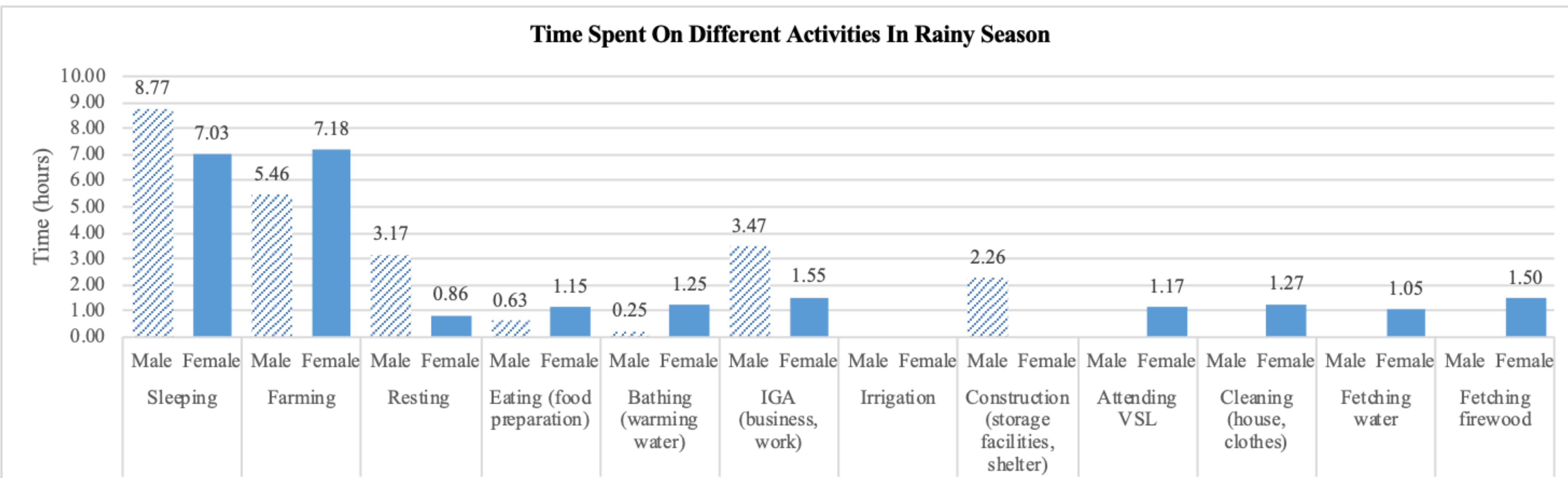


Figure 3-2: Average time spent on activities during the rainy season. (n=187).

More time is also spent by women in preparing meals and bath water. Other activities such as cleaning the house/clothes/children, fetching water, and firewood are only performed by the women with the help of their daughters and in few cases, their sons, helped to fetch firewood and water using bicycles.

3.3.2 Identification of Labour Intensive Tasks and Peak Labour Demand Periods

Women smallholder farmers indicated the most labour intensive tasks and in which months the seasonal labour demands increase. Women farmers identified December to February as the peak labour demand period for the cultivation and May to July as the peak labor demand period for post-harvest tasks.

Table 3-1: Farm Operations and Associated Tools used by Women Farmers' Innovator Groups

FARM OPERATION	TOOLS AND IMPLEMENTS USED.
Crops Grown	Maize, Tobacco, Soya Beans, Sweet Potatoes, Beans, Irish Potatoes, Groundnuts
Land Clearing	Axe, Panga, Hoes, Saw
Land Preparation	Hoe, Panga, Hammers
Seeding	By Hand, Small Hoe
Application of Fertilizer	By Hand, Small Hoe, Sticks,
Pest/ Disease Control	Buckets, Spray Cans, Knap Sacks Sprayers
Watering / Irrigation	Buckets, Watering Cans, Motorized pumps(in groups)
Weeding	Small Hoe
Harvesting	By Hand, Hoes, Sickles, Axes, Pangas
Post-Harvest Processes	Mortar and Pestles, Hand, Shellers And Grinders, Storage Sheds
Marketing	Ox Carts and Bicycles for Transport,

Table 3-2: **Women farmers' responses by Site for Tools Used, Activities Done and Crops Grown during the rainy season.**

Tools Used in January			Activities Done in January			Crops Grown in January		
Tools Used	Location		Activities	Location		Crops	Location	
	Nkhamenya	Kabudula		Nkhamenya	Kabudula		Nkhamenya	Kabudula
Hands	10%	5%	Banking	6%	30%	Beans	10%	13%
Hoes	26%	32%	Fertilizer	13%	9%	Cassava	3%	3%
Needles		5%	Harvesting	2%	3%	Groundnuts	10%	13%
Ox-Carts		5%	Making Ridges	7%	4%	Irish Potatoes	7%	8%
Pangas		9%	Planting	24%	10%	Maize	10%	13%
Plates	6%	14%	Selling	5%	4%	Rice		2%
Sacks		5%	Weeding	35%	40%	Soya Beans	10%	13%
Spoons	16%	14%	Earthing (Uprooting)	1%		Sunflower	10%	7%
Sticks	16%	14%	Applying Chemicals	3%		Sweet Potatoes	9%	13%
Sprayers	13%		Clearing Land	1%		Tobacco	10%	13%
Bottle Tops	3%		Digging Out	1%		Bambara Nuts		2%
Bottles	3%		De-Suckering	1%		Tomatoes	4%	
Legs	6%					Millet	6%	
						Okra	1%	
						Onions	1%	
						Rape (Vegetables)	1%	
						Rice	1%	
						Sorghum	1%	
Total	**100%**	**100%**		**100%**	**100%**		**100%**	**100%**

The table 3.3 above shows responses on tools used and activities undertaken in the month of January of each year based on focus group discussions (FGDs). Common activities of that month include banking, fertilizer application, planting and weeding crops such as beans, ground nuts, maize, soya beans, sunflower and tobacco. Among all tools used during this month of the year, hoes are used the most, followed by plates, spoons and sticks.

More details on the lists and proportions of responses on tools used in the fields, activities and crops that are done and available by month (in the rainy season) are in the supplementary data.

Table 3-3: Responses on Tools Used, Activities Conducted and Crops Grown in the Dry Season.

Tools used in July			Activities Done in July			Crops Grown in July		
Tools used	Location		Activities	Location		Crops	Location	
	Nkhamenya	Kabudula		Nkhamenya	Kabudula		Nkhamenya	Kabudula
Hands	10%	6%	Applying Chemicals	3%	7%	Bambara Nuts		3%
Hoes	7%	21%	Baling	3%	4%	Beans		14%
Needles	2%	3%	Clearing Land	2%	11%	Groundnuts	14%	17%
Ox-Carts	5%	6%	Digging Out	3%	2%	Irish Potatoes		6%
Pangas	2%	3%	Grading	8%	7%	Maize	20%	22%
Sacks	15%	12%	Harvesting	2%	2%	Soya Beans	3%	14%
Sticks	7%		Removing Stalks	8%	4%	Sweet Potatoes	11%	6%
Wheel Barrow	2%	3%	Selling	29%	36%	Tobacco	20%	19%
Winnower	7%		Shelling	10%	9%	Millet	11%	
Bicycle		3%	Slashing	0%	2%	Rape-Vegetables	3%	
Buckets	2%	3%	Storage	0%	2%	Sorghum	3%	
Head	2%	0%	Transport	13%	7%	Sunflower	9%	
Jake	17%	21%	Earthing	0%	7%	Tomatoes	6%	
Strings	7%	3%	Drying	5%				
Car		6%	Nursery Prep	3%				
Shovels	2%	3%	Planting Nurseries	2%				
Sprayers		3%	Storage	5%				
Trucks		3%	Threshing	2%				
Knives	7%		Treating	2%				

Pestle/Mortar	2%		Watering Nurseries	3%				

Results summarized in the table above shows responses on tools used based on responses received during FGDs and activities undertaken in the month of July of each year. Among all tools used during this month of the year, jacks are used the most, followed by hoes, and sacks. Common activities include, selling crops, clearing the land, shelling, grading and transporting crops such as tobacco, maize, beans, ground nuts, soya beans, and sweat potatoes. More details on the activities conducted in the dry season are presented in the supplementary data.

3.3.3 Cultural and Community Days Observed by Innovator Groups.

The innovator groups also indicated when the cultural days mostly occur in the year to better understand when they have more time in the year. These did not include public holidays as the research aimed to collect site specific cultural and community relevant data. The groups indicated the months between May and September as this is when most activities have been completed and not much labour intensive work takes place. In addition, this is also the time when smallholder farmers have more disposable income and can afford to purchase none-essential “luxury” items.

3.3.4 High Income and Expenditure Periods of the Year

Groups were asked to rank the income availability from 1 to 10, with lower scores representing extreme income shortages and high scores representing high income availability. They were also asked to rank the expenditures for each month from 1 to 10, with lower scores representing low to no expenditure and high scores representing high expenditure.

Descriptive statistics were calculated to understand the main sources of income of the farmers after focus group discussions. Table 3.6 below summarizes the sources of income for the two sites. It is therefore shown with respect to these results that farming is the main source of income for the women farmers in both sites followed by small scale businesses, then professional jobs.

Table 3-4: Main Sources of Income for People in Nkhamenya and Kabudula

Income Sources	Nkhamenya	Kabudula
Artisans	1%	3%
Small Scale Businesses	22%	15%
Professional Jobs (Teacher, Policeman Etc.)	15%	11%
Bricklayer	2%	1%
Forest Guards	1%	1%
Farming Only	58%	68%
Total Households	100%	100%

Descriptive statistics were calculated to understand the income ranges of the farmers based on data gathered. The income ranges indicate that majority of farmers fall in the income range of between US$0.00 to US$363.50, indicating lower incomes for most smallholder farmers in the study area.

Table 3-5: Income Ranges for The Farmers in Nkhamenya And Kabudula Areas.

Income Ranges	Nkhamenya	Kabudula
MK 0-199999 (USD 0.00 - 363.65)	73%	51%
MK 200000-499999 (USD 363.65 - 909.09)	19%	27%
MK 500000-999999 (USD 909.09 - 1818.18)	6%	19%
Over MK 1000000 (USD 1818.18)	2%	4%
Totals	**100%**	**100%**

3.3.5 Least Labour Intensive Periods for Women Smallholder Farmers

The innovator groups indicated that they typically experience less labour intensive periods during the post-harvest season (May to September) compared to the cultivation season where they spend many hours on ridging, planting and weeding their farms. They also indicated that on their free time, they typically:

- *Have time to rest i.e. period of no physical activity*
- *Visit family and friends (mostly on Sundays after church)*
- *Start businesses such as retail stores or clothes shops.*
- *Pursue further education to develop themselves e.g. farmer training, financial management*
- *Repair baskets and other household items or ask their husband to repair the farm tools*
- *Make small snacks for sale during market days*
- *Plant vegetables where irrigation permits for sale during market days or to close neighbors*
- *Mend their children's and husband's clothing*

> *"With labour-saving tools, I will have more time to carry out my daily activities without exhausting myself."*
>
> ***Woman Smallholder Farmer - Nkhamenya innovator group***

> *"When we use time-saving tools, we will have the time to visit our friends and family and enjoy their company".*
>
> ***Woman Smallholder Farmer - Kabudula innovator group***

3.3.6 Cropping Calendar for Central and Northern Malawi

Each group in each study area identified the most commonly grown crops and highlighted the yields per acre.

Table 3-6: Breakdown of the cropping basket and yields per crop and per site.

Crops Grown	**Yield Range Per Acre**	
	Nkhamenya	**Kabudula**
Maize	1350 - 1500kg	1350 - 1500kg
Tobacco	200 - 500kg	200 - 500kg
Groundnuts	800 - 1250kg	800 -1250kg
Soya Beans	300 - 500kg	300 - 500kg
Sunflower	150-200kg	150-200kg
Beans	150-200kg	150 - 200kg
Sweet Potatoes	50 - 100 Bags	50 - 100 Bags
Irish Potatoes	500 - 700kg	500 - 700kg
Cassava	50 Bag-100 Bags	
Millet	200kg-350kg	

There were very few differences noted between the two study areas regarding the type of crops they grow. However, cassava and millet are typically grown in the Nkhamenya and not in Kabudula.

3.3.7 Existing Tools in Use during the Seasonal Calendar

Each group identified their farming activities and tools used during the cultivation season as well as those carried out during the post-harvest period of the farming cycle. They then reviewed the list of activities and ranked them based on labour intensity. Tables 3.11 and 3.12 indicates tools currently used for cultivation activities and post-harvest activities respectively.

Table 3-7: Ranking of Tools by Labour Intensity during the Cultivation Season.

	Clearing Land	**Making Ridges**	**Banking Ridges**	**Chemical & Fertilizer Application**	**Weeding**	**Planting**
Most Onerous Task by season (1-5)	5	1	2	6	3	4
Tools Used	Hoe and Panga	Hoe	Hoe	Tea spoons, plates, pop bottles & tops, buckets	Hoe	Sticks (Poles to dig stations), hoes, heels
Tool effectiveness	5	2	2	5	4	4
Tools available in Malawi markets	traditional size hoe	traditional size hoe, animal powered equipment	traditional size hoe, animal powered equipment	traditional and micro size sprayers	traditional size hoe	traditional size hoe, animal powered equipment

As indicated in the table above, during the cultivation period between October and Late March, the most labor-intensive task as per the women smallholder groups is ridging as it uses up a lot of energy and is very time consuming when using the traditional size hoe. The women smallholder farmers also ranked the identified existing cultivation tools' effectiveness per activity and gave a score for effectiveness ranging from 1 to 5 (the lower the score, the higher the effectiveness). The tool identified as most effective for its activity was the traditional hoe when used for ridging. However, this same tool is ranked as least effective for land clearing, planting and weeding as these activities typically don't need a large blade or heavy tool to efficiently complete the task.

Figure 3-3: Existing tools in use in rural Malawi as described by women farmers

Figure 3-4: Existing tools in use in rural Malawi as described by women farmers

Post-harvest season runs from April to September and is typically less labor-intensive. The tasks identified during this season's activities are: *1) shelling maize, 2) threshing soya beans 3) grinding maize and 4) shelling groundnuts*. During this time the most labor-intensive task as per the women smallholder groups is shelling as it is very time consuming by hand since farmers lack of machinery.

Table 3-8: Ranking of Tools by Labour Intensity during the Post-Harvest Season.

	DRY SEASON TASKS						
	Cutting/ Stalking Maize	**Removing Maize Cob Covers &**	**Digging and Uprooting Groundnuts**	**Shelling Maize**	**Threshing Soya and Groundnuts**	**Pounding/ Milling**	**Winnowing**

		Decobbing					
Most Onerous Task by season (1-5)	1	1	2	3	2	4	5
Tools Used	Panga, Hands	Hands	Hands	Hands	Hands, Sticks/Poles, Sacks,	Pestle & Mortar, Mills	Winnower, old sacks.
Tool effectiveness	4	5	5	5	5	4	5
Tools available in Malawi markets	Pangas	N/A	N/A	N/A	Commercial Mills with threshers	Commercial Mills with grinders	Winnower

The women smallholder farmers also ranked the existing post-harvest tools' effectiveness and gave a score for effectiveness ranging from 1 to 5. As there were no other existing tools identified for three of the five labor intensive tasks, other than hands, the ranking as per the women farmers was "least effective". The women indicated that they would prefer to have a tool for these tasks but make do with their hands in the absence of such instruments. The tools identified for cutting maize stalks and threshing grains were also ranked as least effective as they mostly use their hands and locally available sticks/poles for these activities.

Figure 3-5: Existing winnower for Maize and Groundnut winnowing.

Figure 3-6: Existing tool used for pounding/grinding Maize and Groundnuts.

3.3.8 Average Household Labour Distribution.

Each group of women innovators indicated the on-farm tasks carried out by the household members as well as livestock care and general household activities. The women participants also specified who in the household was responsible for the tasks identified to assess the division of labour. Multiple comparison and a descriptive analysis of the tasks was also completed. The tables below are a summary of the activity-specific results based on the responses.

Results in table 3.14 below indicate that women are involved in growing a large range of crops as compared to men who focus more on tobacco. It can therefore be concluded that women therefore have more labour burdens for on-farm activities.

Table 3-9: Division of Labour During Production of Crops.

Example on Growing Cash Crops	Task Done By	
	Women	**Men**
Bambara Nuts	8%	0%
Beans	41%	0%
Cassava	0%	8%
Tobacco	25%	33%
Groundnuts	33%	0%
Maize	0%	8%
Millet	8%	0%
Soya	16%	0%
Sunflower	41%	0%
Sweet Potatoes	8%	0%

Results in table 36 below indicate that women are also involved in selling a large range of crops as compared to men. While women contribute a significant amount of their labour to the growing of tobacco, they are not involved in the selling of tobacco and consequently, the decision making regarding the income generated. This further exasperates the labour and income constraint challenges for women smallholder farmers. Some may question why this is the case when their responses indicate that they sell more crops. This is in fact deceiving since the crops that women farmers are able to grow and sell on their own are usually food crops with very really little income generating capacity as compared to tobacco. For this reason, they are burdened more as a result of having many crops to grow, manage, harvest and market while in the end, they are left with the low returns on the investment of their money, time, energy and little available land.

Table 3-10: Division of Labour During Sale of Cash Crops.

Example of Cash Crops Sold	Percentage of Respondents Involved			
	Women	Men	Girls	Boys
Beans	23%	0%	4%	0%
Groundnuts	38%	9%	4%	4%
Maize	9%	14%	0%	4%
Soya	42%	0%	4%	0%
Sunflower	0%	4%	0%	4%
Tobacco	0%	42%	0%	4%
Vegetables	4%	0.00%	4%	0%

Results in table 37 below also demonstrated a higher labour burden for women smallholder farmers who indicated that they are involved in taking care of more animals as compared to men, boys and girls. The responses indicated that women mainly lead in their labour contribution regarding taking care of goats, chicken, and pigs while they only indicated that men mainly are responsible for cattle and to a small extent, goats as well.

Table 3-11: Division of Labour During Care of Livestock

Examples of Livestock	Percentage of Respondents Involved			
	Women	Men	Girls	Boys
Cattle	3%	28%	3%	14%
Chicken	25%	0%	3%	3%
Goats	28%	3%	10%	0%
Pigeons	3%	0%	3%	0%
Pigs	21%	0%	10%	0%
Sheep	3%	0%	3%	0%

Results relating to selling livestock indicate that women are mostly involved in selling small animals as compared to men. These are small animals that generate little income e.g. poultry, goats and pigs. Large animals that generate higher sums of income such as sheep and cattle are sold by men who control any income generated.

Table 3-12: Division of Labour During Sale of Livestock

Examples of Livestock Sold	Task Done By			
	Women	Men	Girls	Boys
Cattle	0%	23.81%	0%	0%
Chicken	61.90%	4.76%	4.76%	4.76%
Goats	19.05%	9.52%	0%	4.76%
Pigeons	4.76%	0%	0%	0%
Pigs	19.05%	9.52%	0%	0%
Sheep	0%	4.76%	0%	0%

Culturally speaking, building houses is typically men's responsibility. However, detailed discussions revealed that there are some tasks that require assistance from women and girls. For example, the results showed a high involvement of women in assisting in building homes. It can therefore be concluded that women play a significant role in building homes and contribute significantly to the labour force. This further highlights their labour constraints as they are not only responsible for their "female" household tasks but also support their male counterparts during construction of structures.

Table 3-13: Labour Distribution When Building Houses, Sheds, Barns

Examples of Tasks When Building Houses	Task Done By		
	Women	Girls	Boys
Cooking	7%	0%	0%
Draw Water	50%	43%	3%
Gather and Transport Grass	3%	3%	0%
Heading Poles	3%	3%	0%
Mold Bricks	7%	7%	0%
Mortar	3%	0%	0%
Pass Mud	0%	0%	3%
Serve with Grass	3%	3%	3%
Serving Bricks	10%	3%	3%

Results regarding making or repairing of tools indicate that women farmers are mostly involved in sharpening of tools and purchasing them to a small extent but for the most part, it is men who replace handles and repair tools. This research aimed to assess whether this is because the women are not given the opportunity or whether it was due to a lack of capacity. This is reported in chapter 4, (from page 91) of this thesis paper.

Table 3-14: Labour Distribution in Relation to Making/Repairing or Buying Tools

Examples in relation to making/repairing or buying tools	Task done by				
	Women	Men	Girls	Boys	Hired labor

buy hoes	4%	8%	0%	0%	0%
make tools	0%	4%	0%	0%	4%
repair tools	0%	4%	0%	0%	0%
replace handles	0%	19%	0%	0%	0%
sharpen hoes	42%	15%	8%	12%	0%
sharpening tools	0%	4%	0%	0%	0%

The results regarding post-harvest activities continue indicate that women are involved in most of the associated activities and therefore have the higher labour burden. Based on the responses given during the FGDs, women farmers are involved in many more post-harvest tasks as compared to men.

Table 3-15: Labour Distribution in Post-Harvest Tasks

Examples Related to Post Harvest Tasks	Task Done By			
	Women	**Men**	**Girls**	**Boys**
Applying Chemicals	0%	5%	0%	0%
Bailing	5%	23%	0%	0%
Cutting	0%	5%	0%	0%
Grading Tobacco	5%	36%	0%	5%
Harvesting Maize	5%	0%	0%	0%
Harvesting Beans	5%	0%	0%	0%
Harvesting Groundnuts	9%	0%	0%	0%
Harvesting Soya	5%	0%	0%	0%
Packing	5%	0%	0%	0%
Pounding	5%	0%	0%	0%
Removing Cobs	5%	0%	0%	0%
Shelling Groundnuts	5%	0%	0%	0%
Shelling Maize	9%	0%	5%	5%
Stocking	0%	5%	0%	0%
Storage	9%	0%	0%	0%
Transport	0%	9%	0%	5%
Winnowing	27%	0%	5%	0%

In general, findings indicate that women are primarily responsible for household maintenance and food preparation as well as caring for children at both sites. Collection of water is also a female role where the girls also have a significant labour contribution. Boys will sometimes assist to collect water for construction of houses, sheds and granaries. Men are on average responsible for less than half of the household and on-farm tasks (38 per cent), while women are primarily responsible for almost 55 per cent and assist in almost all household and on-farm tasks.

Purchase of tools is not done by girls in any of the surveyed households. Livestock care is similarly viewed and carried out by men with the assistance of their boys. Women and girls do not take part in this activity for large animals like cattle. The care and sale of cattle is the man’s responsibility. The women who took part in the focus groups indicated that these assets were usually owned by the men while women owned and cared for little animals like chicken and pigs. However, they would still need to consult with their husbands regarding the sale of smaller assets. More examples relating to the mapping of labour distribution by task are detailed in the supplementary data and appendices document. Based on these findings, chapter 4 outlines the processes undertaken to co-design labour saving tools with women farmers based on the labour constraints identified including cultivation tasks such as ridging and weeding as well as time consuming tasks such as maize and groundnut shelling.

3.3.9 Mapping of Human, Natural and Other Resources in Malawi

Women innovator groups mapped out the available human, natural and other resources in their community and indicated the challenges they face when trying to access these resources.

Table 3-16: Mapping of Available Resources in the Study Area.

Site 1	**Kabudula**	**Site 2**	**Nkhamenya**
Chitukula	Hospitals, Schools, Boreholes, EPAs and Extension Workers, Markets, Police Stations, Post Offices, Wells, Roads, Bridges, Churches, Filling Stations, Mobile Network Tower, ADMARC, Tool Producers	**Lodjwa**	Schools, Hospitals, EPAs and Extension Workers, ADMARC, Markets, Boreholes, Agricultural Organizations, Churches, Roads, Bridges, Tool Producers
Lukira	Markets, Schools, EPAs and Extension Workers, Post Offices, Police Stations, Boreholes, Wells, Hospitals, ADMARC, Roads and Bridges, Tool Producers	**Kavikula**	Tool Producers, Post Offices, Schools, Markets, Churches, PSP, Hospitals, Boreholes, Wells, Police Stations, EPAs and Extension Workers, ADMARC, Roads, Bridges, Filling Station, Tool Producers
Mkuta	Filling Station, Schools, Post Offices, Police Station, Churches, Hospitals, Agricultural Organizations, Boreholes, Wells, Markets, EPAs and Extension Workers, ADMARC, Roads, Bridges, Mobile Network Towers, Tool Producers	**Kavidebwere**	Hospitals, ADMARC, EPAs and Extension Workers, Police Stations, Markets, Post Office, Schools, Churches, Boreholes, Agricultural Organization, Roads, Bridges, Filling Station, Tool Producers
Kalumba	Schools, Police Stations, Post Offices, EPAs and Extension Workers, Filling Stations, Churches, Markets, ADMARC, Boreholes, Wells, Hospitals, Roads and Bridges, Tool Producers		

Table 3-17: Mapping of Naturally Occurring Resources in in the Study Area.

Site 1	Kabudula	Site 2	Nkhamenya
Chitukula	Land, Wetlands, River, Forests	Lodjwa	Hills/mountains, Land, Wetlands, Rivers, Forests
Lukira	Land, Wetlands, Rivers	Kavikula	Wetlands, Land, Hills/mountains, Marsh, Game reserve, Forests
Kalumba	Land, Wetlands, River,	Kavidebwere	Land, Hills/mountains, Rivers, Wetlands, Mountain Ranges
Mkuta	Land, Wetlands, Rivers, Mini Forest		

Table 3-18: Tool Mechanization Access

Energy Source	Uses of Energy Source	Tool Mechanization Access	
		Kabudula	**Nkhamenya**
Paraffin/Candles	For Lighting	Assorted Lamps (metal, glass) Available at trading centers	Assorted Lamps (metal, glass) Available at trading centers
Firewood	Cooking and Curing Tobacco For Cooking	Hand Tools (Hoes, Pangas, Axes…)	Hand Tools (Hoes, Pangas, Axes…)
Charcoal	Cooking	Few improved stoves Use of 3-stone method	Few improved stoves Use of 3-stone method
Animals	Pulling Ploughs Pulling Carts-Transport	Animal Pulled Plough/Ridger	Animal Pulled Plough/Ridger
Electricity	Milling, Charging Stations	Milling Stations available in villages	Milling Stations available in villages
Solar Panels	Lighting, Charging, Radios	Around trading centers	Around trading centers

On the other hand, in Nkhamenya, respondents indicated that they had better access to welders and some of the surveyed smallholder farmers had access to advanced animal-drawn tools. Similar to the Kabudula focus group discussions, very few of the smallholder farmers indicated that they had electricity in their homes (<3 per cent). However, in Nkhamenya, people reported to have easier and more access to different modern power sources (electricity, solar) than in Kabudula.

3.3.10 Assessment of Existing Agricultural Tools in Malawi

Following the completion of the resource mapping exercise, the women smallholder groups were further engaged to analyze the existing tools that are currently in use for the identified labour intensive tasks. Each innovator group was asked to bring the tools they presently use for land clearing, ridging, planting, weeding and chemical application. Each tool's dimensions were captured and recorded for the:

1. *Tool Weight,*
2. *Handle Length,*
3. *Blade Length, Width and Weight.*

Each tool was then labeled for further discussion with the women smallholder farmers. Each focus group was asked to comment on the existing tool's dimensions with regards to the activity in question and suggest refinements to make the tool time and energy saving or make recommendations for new technologies. Therefore, the research assessed the existing tools used for the farmer-identified labour intensive activities during the cultivation period.

For the post-harvest season, women smallholder farmers indicated that they had no machines to complete the processing activities for the labour intensive tasks they identified. Each innovator group was asked to describe how they *1) shell maize, 2) grind maize, 3) shell and winnow groundnuts, 4) thresh soya beans and common beans.* The women smallholder farmers indicated that they use their hands for shelling maize and ground nuts, winnowers for groundnut cleaning, pestle and mortar to grind maize and sticks and poles to thresh soya beans and common beans. Table 3.28 shows the assessment results for the existing tools used for the farmer-identified labour intensive activities during the post-harvest period.

Table 3-19: Recommended Tool Handle Lengths Compared to Existing Tools

Current and Women Smallholder Farmers' Recommended Tool Handle Lengths				
Type of Tool Used	**Current dimensions (cms)**	**Farmer-Recommended Dimensions (cms)**		
		Kabudula	**Nkhamenya**	**Average**
Clearing hoe	92.00	79.90	87.20	83.55
Ridging/Banking hoe	92.00	80.29	85.44	82.86
Weeding hoe	91.00	82.28	89.75	86.01
Sasakawa planting hoe	52.00	45.20	59.38	52.29

3.4. Discussion and Conclusions

There are very few discordances in the surveyed parts of Malawi indicating a similar household structure in distribution of labour. In both study areas, the women are primarily responsible for household maintenance and food preparation as well as caring for children. Collection of water is also a female role where the girls also have a significant labour contribution. Boys will sometimes assist to collect water for construction of houses, sheds and granaries, which men are responsible for (15/186 households). Men are on average responsible for roughly 38 per cent of household and on-farm tasks, while women are primarily responsible for around 55 per cent. As observed in this study, and many developing contexts, men are often responsible of producing cash crops and tending to large animals (e.g. tobacco and cattle), while women are responsible for producing subsistence crops for home consumption (e.g. goats, pigs, sheep and maize) (Doss, 2002, Starkey and Mutagubya, 1992).

Purchase of tools is not done by girls in any of the surveyed households. This implies that this task is still primarily viewed as a "male" role. Livestock care is similarly viewed and carried out by men with the assistance of their boys. Women and girls do not take part in this activity for large animals like cattle. The care and sale of cattle is the man's responsibility. The women who took part in the focus groups indicated that these assets were usually owned by the men while women owned and cared for little animals like chicken and pigs. However, they would still need to consult with their husbands regarding the sale of smaller assets. This indicates a gender imbalance and disempowerment for the women smallholder farmers who would like to contribute to the decision making regarding the sale of large and small assets (Gawaya, 2008).

Women are involved in almost all household and farming activities and spend little time to sleep and rest during most times of the day as compared to male farmers (FAO, 2011b). These findings were supported by this research where results show that during both dry and wet seasons, women spend more time doing farm-work than men. Men spend more time in various higher income-generating activities than women (FAO, 2011a, Mathiassen et al., 2007). It was also observed (Von Braun and Webb, 1989) that activities incorporating the use of technology are usually done by men e.g. using a tractor, plough or animal cart. This study has found out that on average, men spend 12.5 hours resting while females spend only 8 hours and these findings are supported by (Blackden and Wodon, 2006) who just as was observed in this research, noted that there are marked differences in how much time is given and on which tasks men and women spend their time on and off the farm. This research finding also noted that more time is spent by women in tasks only they perform, sometimes with assistance from their daughters. These include preparing meals and managing other activities such as cleaning the house, doing family laundry, caring for children as well as fetching water, and firewood.

3.4.1 Peak Labour Demand Periods and Cost of Labour

This analysis was done to increase the understanding of the importance of labor and its availability for production. According to (Collier and Dercon, 2014), labor productivity is among key factors that have to be considered in developing contexts. Women farmers in this research identified December to February as the peak labour demand period for the cultivation in Malawi and May to July as the peak labor demand period for post-harvest tasks. This is in line with the country's unimodal rainfall patterns which explains the peak in labour requirements as reported by (USAID, 2017). During this time, smallholder farmers who can afford to will hire temporary labour to complete the labor-intensive activities (ridging, banking and weeding) (USAID, 2017, Takane, 2008) during the cultivation time and the cutting of maize stalks and grinding of maize. The table below provides a summary of the seasonal calendar as well as the common tools that are used as well as common crops during each month of the year. Farmers in Malawi rely heavily on simple hand-held tools such as hoes, panga knives, sprayers, watering cans and manual labour, mostly made up of the members of the household and hired labour, where affordable (IFAD/FAO/FARMESA). Based on the seasonal assessment data collected by this stage of the research, the study also observed that there was a higher labour demand during the cultivation season as compared to the post-harvest season.

3.4.2 Cultural and Community Days Observed by Innovator Groups.

The women innovator groups' feedback on when the cultural days mostly occur in the year was used to determine when marketing agricultural tools or other products was most feasible as well as to efficiently plan the co-design, prototyping and testing of the innovations from this research. The groups indicated that community and cultural events typically take place between May and September, when most activities have been completed and not much labour intensive work takes place. Even though the labour peaks identified for the post-harvest period were between May and July, the feedback from women smallholder farmers was that these post-harvest tasks were typically completed by many family members. In addition, as this is the post-harvest period, this is also the time when smallholder farmers have more disposable income and can afford to purchase more improved tools, if available in the markets.

3.4.3 High Income and Expenditure Periods of the Year

According to (Chen et al., 2010), household composition and the gender mix of individuals in the household may lead to variations in decision making to use different tools. This research considered these factors and therefore recorded the income and expenditure peak periods to have a better sense of when to market tools to farmers in the surveyed regions of Malawi. In both regions, May to August were ranked as the months with the most income while November, January and February were ranked as the months with the least available income. The peak expenditure periods indicated for both sites were December to February and May to August, when post-harvest income is generated and farmers have more disposable income to purchase new farm inputs and implements as well as personal items.

3.4.4 Labour Intensive Periods for Women Smallholder Farmers

Women farmers indicated that they typically experience less labor-intensive periods during the post-harvest season compared to the cultivation season where they spend many hours on ridging, planting and weeding their farms. The respondents expressed concern at the lack of rest time as this is typically when they are managing household chores such as washing dishes or taking a bath. Refer to section 3.4.1 for more information on the activity clocks outputs.

3.4.5 Existing Tools in Use during the Seasonal Calendar

The tasks identified by women farmers as labour intensive during the cultivation season activities are*: 1) ridging and banking, 2) weeding, 3) planting and 4) land clearing.* The most labor-intensive task was ridging as it uses up a lot of energy and is very time-consuming. The tool identified as most effective for its activity was the traditional hoe. However, this same tool is ranked as least effective for land clearing, planting and weeding as these activities typically don't need a large blade or heavy tool to efficiently complete the task. The resulting effect is that smallholder farmers exert unnecessarily high levels of energy and commit more time that could otherwise be significantly reduced with the right kind of equipment.

The post-harvest period is typically less labor-intensive and the tasks identified as labor-intensive are: *1) shelling maize, 2) threshing soya beans 3) grinding maize and 4) shelling groundnuts.* During this time, the most labor-intensive task is shelling as it is very time-consuming by hand due to a lack of machines. As there were no existing tools identified for three labor-intensive tasks, the tool ranking was "least effective". The tools identified for cutting maize stalks and threshing grains were also ranked as least effective as they mostly use their hands and locally available sticks/poles for these respective activities.

Based on the feedback from the women innovator groups and the results of the analysis above, for smallholder farmers to significantly boost their labour productivity, there was a clear need and strong demand for the design and development of improved cultivation and post-harvest labour-saving technologies. Smallholder farmers expressed a strong need for these improved technologies that can enable them to increase their yields and be more time efficient to save their time and energy for other income generating activities that can contribute to improving their livelihoods.

3.4.6 Human, Natural and Other Resources in Malawi

Women smallholder farmer innovator groups mapped the locations of their villages, farms, irrigation plots, as well as their firewood, vegetable and water collection points. They also identified and mapped out their available human and other natural and other resources in the community and indicated the access gaps and challenges they face. This revealed that the women smallholders had limited access to money/income and land, and had little to no access to electricity, formal education, and sanitation and farm power/energy sources in their villages. On average, a woman smallholder farmer would have to walk up to 2 hours to the nearest trading center to access farming tools, inputs, and implements as well as health care, financial and agricultural support services.

There is very limited access to welders, and none of the surveyed smallholder farmers had access to advanced animal-drawn tools. In addition, very few indicated that they had electricity in their homes (<3 per cent). This highlighted the challenges and limited resources available in the surveyed region. On the other hand, in the Northern region, respondents indicated that they had better access to welders and some of the surveyed smallholder farmers had access to advanced animal-drawn tools. This highlighted the challenges and limited resources available in this surveyed region too. However, in the Northern region, people reported to have easier and more access to different modern power sources than in the Central region (electricity, solar).

3.4.7 Existing Agricultural Tools in Malawi

Resource mapping conducted with all the women smallholder innovator groups revealed a major lack of access to most basic tools. For instance, the only available hoe in the market is produced in a traditional size that the women smallholder farmers have to use for all farming activities. Irrelevant technologies and lack of ownership of these technologies has led to non-adoption of tools that have been produced and introduced to the farmers from various previous research (Sims and Bentley, 2002, Pham and Gault, 1998). Malawian smallholder farmers assessed remain heavily reliant on the most basic tools and implements and are in great need of exposure, education and access to mechanized and improved labor-saving technologies and tools for both food security and economic development as reported by other researchers (Loevinsohn et al., 2013). As studies have proven, mechanization of agricultural tools and implements is crucial to increasing smallholder farmers agricultural productivity (Loevinsohn et al., 2013, Alene, 2010).

Farmers with small irregular farm sizes, low capital, who lack professional jobs and awareness and skills are more likely to continue depending on hand held tools, in addition to the rarely available animal powered implements and non-motorized agricultural machinery (Shrestha, 2012). Following the completion of the existing tools assessment, the women smallholder groups gave their feedback on their use for the identified labour intensive tasks. Each innovator group indicated a high need for improved and customized tools because different activities had their unique tool specifications to make it a good quality and efficient tool. (Kienzle and Murray, 1998), observed concerns about the tools used by female farmers and the work they do. It highlights the cultural, social and gender related constraints the women raised mainly due to the unavailability of better quality and more appropriate production tools. For the post-harvest season, women smallholder farmers indicated that they had no machines to complete the processing activities for the tasks they identified and do most things by hand. In each group consulted, the existing tools did not meet the labour-saving expectations of the smallholder farmers but a lack of resources limits their ability to purchase suitable mechanized equipment. In addition, based on the results of the resource mapping, there are limited labour-saving innovations available in Malawi which makes the limited ones even less accessible to smallholder farmers.

Particular attention must be paid to the gender differences in household and on-farm roles considering the cultural and social context. The overall review of the labour intensive tasks and existing tools shows that women smallholder farmers can be engaged and motivated to analyze their current environment and conditions and make value-adding contributions on how to improve their farming tools and methods sustainable to increase their labour productivity and overall household efficiency for on and off farm activities. The results of this research also indicate a need for improved agricultural tools that are tailored to the needs and resources available to smallholder farmers. The next chapter provides a detailed overview of the investigation conducted to assess the potential for these women innovator groups to co-develop feasible technology designs for their labor-intensive agricultural activities.

4. CHAPTER 4: CO-DESIGN AND PRODUCTION OF AGRI-TECHNOLOGIES

4.1. Background on Malawian Markets for Agricultural Tools and Technologies

The Hand tools are very important implements for smallholder farming throughout Sub-Saharan Africa but labor productivity of female smallholder farmers in particular in Malawi is constrained by lack of access to labor-saving technologies and improvement of the most basic hand held farm tools (Murray et al., 2016). They are used in most countries in this region for clearing land, soil tilling, during planting, weeding and as well as during harvesting of crops (Sims and Kienzle, 2006). These very arduous task which in rural areas of many developing countries is mainly done by women (Ashburner and Kienzle, 2013).

While there are many mechanized and fuel powered technologies for cultivation and post-harvest tasks, the typical smallholder farmer cannot afford them and are left to rely on the basic traditional size hoe. This tool is used for most farming activities (Murray et al., 2016, Chirwa and Matita, 2012), where hands and feet cannot be used. Other tools such as slashers, long knives and axes are also used but these also require manual labour. Post-harvest processing machines are available for shelling maize, grinding maize, shelling groundnuts, among others (Abass et al., 2013, Dunmade, 2005). However, these are not currently affordable or accessible and consequently, the smallholder farmers have to use their hands for these time-consuming and labour-intensive activities. Poles and sticks are also locally sourced for threshing grain.

4.2. Research Objectives

- *To develop designs of new and improved labour-saving and productivity enhancing tool designs for cultivation and post-harvesting, based on preferences of the women farmer innovator groups.*
- *To investigate and select the most feasible and viable rapid prototyping technology from 3 options: 3D printed, arc welded and metal cast prototypes.*

4.3. Research Methodology

This chapter summarizes the participatory design methodology that was utilized test the potential of women farmer innovator groups to co-design labor-saving tools that can be rapidly prototyped to their preferences in an enabling environment. Specifically, this paper outlines the mixed approaches used to capture the technology design ideas and inputs of the women smallholder farmers in Lilongwe and Kasungu districts across the Central region of Malawi.

The “best-bet” innovator groups made up of women smallholder farmers were expected to actively participate in the creative co-design sessions to develop improved tools that will reduce their household labour intensive work during peak seasons. The aim of the co-design phases was to capture insight/contributions from different participants including the women innovators who were at the center of the creative co-design spaces, the technical backstopping from the research team, the locally identified fabricators and agri-engineering departments from the university and Government resrach station. The study also aimed to incorporate any prior knowledge and documentation relating to existing tool designs that were yet to be prototyped by the stakeholder mentioned that had the potential to infuence the design process.

In addition to testing the women farmers’ innovative capacity, the potential to source and apply rapid prototyping technology in a rural or semi-urban setting was also explored during this phase of the research with the aim of creating an innovative user-driven culture geared towards sustainable entrepreneurship development. The research tested three different rapid prototyping methods i.e. local welding using scrap materials, metal casting and industrial grade arc welding. The follow criteria was applied when testing the rapid prototyping options;

- *User friendly capacity,*
- *Cost-effectiveness*
- *Feasibility for application in Malawi*.

4.3.1 Engagement with Innovator Groups

The focus of the research was to explore the potential for selected women smallholders i.e. innovators to design proposed improvements to the selected existing tools to be prototyped for further on-farm assessment. The women's ideas and opinions were recorded, interpreted and then translated into initial prototype designs, through a rigourous, frequent and interactive process of discussion, reflection and brainstorming. Each week, the research team visited the innovator groups on rotation to capture their ideas, and document their inputs over a 2-3 hour session including drafting of 2-D sketches on paper to further express their thoughts and get their messages across to the faciliator. The note taker translated every contibution from the women in each innovator group and these were further reviewed and developed to complete the design process for each tool produced through this co-design process. The chapter below will outline each of these design processes in more detail. The reseach team worked to engage the innovator groups in a standardized way and developed appropriate tools to capture the data from the women farmers. Through this substantial process of communication that made all participants equals and with the reseracher in the crucial intermediary role, the discussions were focused and allowed the groups to reflect on their experiences ad share their ideas on how to co-design improved tools that will enable them to save their energy and time.

4.3.2 Sampling Frame

This study applied a purposive sampling method following a specific design that was relevant to the research (Bryman, 2012, Etikan et al., 2016). The innovation screening criteria was thus designed for this study to identify innovator women smallholder farmers (chapter 2, page 30). The choice of techniques used in this study depended on the type and nature of this research that focussed only on innovators (female farmers). Details of this innovator assessment are provided in chapter 2 of this research thesis paper.

4.3.3 Materials

For each session, each group was given note books, pens, flip charts, pencils, rulers, protractors and erasers to use for drawing their 2-dimensional designs. In some cases, the participants preferred to draw on the ground using sticks and later sketched them in their notebooks.

4.3.4 Data Collection Techniques

Each agri-tool co-design session involved 10-12 women from 1 innovator group. To ensure that each group member had adequate exposure and a good understanding of what “labour-saving” technologies were, the innovator groups were introduced to various types of hand and fuel-powered tools and technologies that were available in Malawi and other countries in the world i.e. Kenya, South Africa, Ethiopia, Zambia, Burkina Faso, Senegal, as well as countries in Europe and America. This was crucial to enable the farmers to critically think of what they were exposed to and to challenge them to come up with a tailored way of designing the tools or to recommend changes to the tools to serve their needs.

The user participation and engagement was very important as every bit of knowledge that the target groups acquired regarding how the tools operate was key in enhancing their understanding of the mechanicals of the tools. As the final end-users who will be working with the equipment, this exposure and added technical capacity simplified the adoption of tools and their general mindset (Singh and Agarwal, 2009).

The facilitator encouraged each group and asked them to provide their inputs on whether their existing (cultivation and post-harvest) tools worked well enough for their (cultivation and post-harvest) tasks. In addition, they were asked to give their value-adding contributions on how to improve the existing tools to make them less time and energy consuming. Focus group discussions were held regularly with women smallholder farmer innovator groups to generate data relating to tools used during high peak seasons, perceptions regarding how to improve existing tools and co-design sessions to develop tool prototypes of the labor-saving tools their wanted.

During the focus group discussions, the researcher facilitated each session and the note-taker recorded the discussions of each group. Semi-structured questionnaires and checklists with open-ended questions were administered by the help of the research facilitator who guided the discussions for each session. The note taker/translator asked the translated versions of the questions in the most common local language (Chichewa) and took detailed notes of the entire sessions. The method enabled collection of both qualitative and quantitative data that was used during statistical analyses. The focus group sessions were also used to gather data for existing tool assessment, refinement suggestions for existing tools and co-design of labour-saving tools.

The research was designed to allow open and enabling creative co-design spaces, borrowing elements of the IDEO Human Centers design process (IDEO.org, 2015), where the women farmer innovator groups focused on what they considered to be labour intensive. Each women smallholder farmer innovator group identified their top 5 labour intensive activities for both the cultivation and post-harvest periods and ranked them in order of intensity. In addition, they identified the existing tools that are currently in use and ranked them for effectiveness in completing the required task. This data was very crucial as this research component also involved a review of existing tool portfolio for each of the high-labour tasks that could be available in or outside of Malawi.

To develop the designs in a participatory manner, each group was asked to give their preferred dimensions, to draw up all the ideas for new tool concepts to compare them to their existing tools used. Selected group participants physically demonstrated their activities through a mock-up of how they carried out the tasks. They also provided justifications for their proposed ideas and refinements where applicable to ensure that they understood the aim of the research which was to develop labour-saving tools.

For each design, the participants were asked to provide details on the dimensions including the tool's length, width and angling for all the parts of the tools. Farmers were also asked to choose 3 angle preferences for required handle to blade connections. The group was then asked to either support or reject the contributions based on constructive feedback. For each identified activity, the women smallholder farmers discussed the innovations and gave constructive feedback on the advantages and disadvantages of each proposed invention. Other alternatives were requested when smallholder farmers rejected the contribution made to ensure that none of the participants felt left out or unappreciated and to ensure that the overall objective of coming up with "better" tool was achieved. They then discussed among themselves to decide whether as a group they agreed on the proposed concepts. The researchers then reviewed the new design concepts and features with each innovator group to come to an agreement on the draft concepts.

Through these diverse, consistent and multiple focus group interactions, each group identified and designed 2-dimensional concepts for the desired tools for cultivation and post-harvest activities. Below is a summary of the season-specific 2D outputs for cultivation and post-harvest labour-saving prototypes.

Table 4-1: Tool Innovations/Improvements Suggested by Women Farmer Innovator Groups

High Labour Tasks Identified in the Cultivation Season	**Concepts for Cultivation Season Labour-Saving Prototypes Proposed by Women smallholder farmer Innovator Groups**
Fertilizer Application	Ergonomic hand protection gear
Agrochemical Application	Ergonomic hand protection gear
Clearing Land	Customized land clearing hoe
Making Ridges & Banking	Customized Ridging and banking hoes, Hand-powered Banker
Planting	Customized planting hoes: Sasakawa (1-seed) and 2/3 seed planting Customized planter for Sasakawa planting
Weeding	Customized weeding hoes and weeders

Figure 4-1: Smallholder Farmers Participate in Tool Co-Design sessions.

Table 4-2: Tool innovations/improvements suggested by Women Farmer Innovator Groups

High Labour Tasks Identified in the Post-Harvest Season	Concepts for Post-Harvest Labour-Saving Prototypes Proposed by Women smallholder farmer Innovator Groups
Cutting & Stalking	Ergonomic Hand Gear, Improved Handles for Existing Tools
Pounding	Hand-Powered Pounder to Replace the Traditional Pestle and Mortar
Removing covers & cobs	Hand-Held Maize Stripper to Remove Covers and Ergonomic Hand Protective Gear for Removing Cobs
Shelling	Maize, Groundnut, Soya Shellers (Hand Held and Hand-Powered Portable)
Threshing	Groundnut, Bean and Soya Threshers
Winnowing	Winnowing and Blower Machines to Replace the Winnower

Each concept was designed in detail describing the dimensions and rationale for selecting the specifications. The designs for new tools were then compared for each group and similar ones were grouped together for further refinements through focus group discussions. All the tool designs that have been co-developed by the women farmer innovator groups are fully traceable/attributable to the women farmer innovator group as each design concept was recorded by group.

4.3.5 Consultations with Local Engineers at Academic Research Institutions

Key informant interviews were conducted with experts from academic and research institutions. The facilitator engaged the expertise of the Department of Agricultural Research Services (DARS) and the support of the agricultural engineering department at the Lilongwe University of Agriculture and Natural Resources at Bunda College (LUANAR). This allowed the research to review the existing technologies being tested at the institution and during the co-design process, each design from the innovator groups was also further reviewed. The engineers offered their local expertise and support to review the ideas for feasibility of local prototyping and testing which enabled the research to determine which prototypes to focus on. The lead investigator ensured that the feedback from the local experts was shared with the farmer innovator groups to further improve the concepts that were designed and reviewed.

4.3.6 Consultations with Local Tool Producers

It was initially anticipated that the women would make their designs using local materials with the assumption that these could easily be sourced in Malawi. However, the results of the resource mapping sessions revealed a lack of both energy sources and quality local materials in the villages. Hence, it was important to link up with local tool producers in the capital city and larger towns who had regular access to tool producing machinery and had the ability to source materials from within the catchment areas that the research could use to produce cost-effective working prototypes for on-farm testing. Key informant interviews were conducted with local producers who indicated that they had an affordable and reliable source of raw materials to produce the designed tools and it was ensured that the feedback from the local experts was shared with the innovator groups to further improve the concepts that were designed and reviewed.

4.3.7 Prototyping Phase of Co-Designed Innovations

Before the actual prototyping work, each design was captured in 2-dimensional formats and recorded for each group that came up with innovations. Repeated designs were also recorded accordingly. The 2-dimensional drawings were then used to attempt two rapid prototyping methods:

3D Printing

The two-dimension (2D) sketches from the women innovators groups were converted into three-dimensional (3D) computer aided design (CAD) files using free online software (123 Design). This generated positive interest and support from 3D printing companies who provided in-kind contributions including:

- *MakerBot Industries: they donated two desktop 3D printers to the research and were instrumental in the testing of 3D printing capabilities for application in developing countries like Malawi*

- *Dreambox Emergence: they supported the research through the donation of "Solidworks" CAD software. This was very beneficial to the research as it made it possible to test other drawing capabilities that were not available on the free online platforms.*

The research had initially considered the use of a 3D scanner to convert the existing and new tool designs to 3D CAD files. However, due to the limited number of existing tools and lack of affordable robust 3D scanners, the research opted for a more cost-effective and practical approach of converting designs from 2D drawings to 3D designs using the CAD software mentioned above.

The first step for the 3D work was the production of biodegradable plastic prototypes of tool components using the donated 3D printer in Malawi. The research applied a mixed-prototyping approach involving local producers and local materials combined with 3D printing of tool parts. This made the process more participatory and innovative as well as faster. This approach also allowed the research to integrate cost-effective 3D printing techniques which is a nascent and rapidly changing technology into the user-driven design process. This significantly reduced the manufacturing process and allowed the research to achieve its objectives within the planned research period.

Cultivation Tools: The completed 2D designs for the cultivation tools were converted into 3D CAD files. Each design was transferred to the desktop 3D replicator to produce micro prototypes according to the CAD files linked to the 3D printer.

Post-harvest Tools: As the post-harvest co-designed innovations were large in size compared to the 3D printing platform on the MakerBot replicator, the 3D CAD files were produced in smaller components and sent to the 3D printer for replication. The printed parts were later assembled and permanently attached as micro prototypes.

Local Welding

The research identified local welders who had regular access to resources to produce the testing prototypes in the most cost-effective manner. The designed 3D files were printed on the MakerBot donated 3D printers and used as a basis for communicating designs to the locally identified tool welders who were engaged for production of prototypes to be used as testing tools. The long-term goal was that the tools that passed the initial testing phase would then be metal cast by local artisans so that metal prototype tools designed by the women smallholder farmers can be produced.

Each of the 3D printed tools was replicated using arc welding and was produced to scale using locally available resources. The tool blades were produced using scrap metal and flat sheets and were then cut to shape based on the 3D printed visual representations. The handles were made from locally available timber and were connected to the blades using screws or bolts and nuts where available. The handle to blade connectors were welded together. The materials used and prototyping methods chosen were selected with long term considerations for tool maintenance and availability of local spare parts.

Figure 7b: A local artisan welds pieces of scrap metal to produce prototypes for on-farm testing.

Metal Casting

The 3rd rapid prototyping approach was metal casting of the prototypes to test whether those produced using metal casting were stronger and more durable as compared to those produced using local arc welding. The prototypes were produced with more durable quality metal (hardened steel) and with refined dimensions (height, weight, thickness of blades, and location of connector) that were determined after additional consultations with the women innovator groups and on-farm trials on time taken per activity.

The producers used the 3D printed micro-prototypes to metal cast the tools to scale using the provided dimensions. The specifications of each prototype were conceptualized and tailored to the preferences of the women smallholder farmers to further test the metal cast tools. The tool prototypes were produced in South Africa as there were no metal casting companies in Malawi with the capacity to produce the required tools at the time this research was conducted. A total of 7 prototypes were produced and each prototype was produced in triplicate for field testing to account for 3 handle preferences based on previous farmer/user feedback.

4.4. Results

4.4.1 Current Tool Designers

The research mapped and engaged 31 local tool producers identified by women farmers from within their communities. Most of them sell traditional hand-hoes and other hand-held tools such as slashers and knives. These tools are not customized and are not produced with the goal of reducing time and energy constraints for the end-user. In addition, the end-user is not engaged during the tool development process and cannot give ideas on the design they need. Most respondents indicated that the tools sold are those that local artisans can afford to produce for sale.

4.4.2 Proposed designs for cultivation tools

Women farmers indicated that all agricultural tools should be customized to each labor-intensive task. For all existing tools, there were no handle to blade connectors as the existing blade is typically attached to a piece of wood cut from a tree with no consideration to ergonomic or safety measures. The hoe is assembled by making a hole through the bottom thicker end of a tree branch and sticking the pin end of the hoe blade in. Many women farmers raised their safety concerns as the blade often got detached during farming activities. As most women carry their children on their backs while they work, the handle to blade connector innovation was rated as necessary to ensure the safety of the farmers and children in their care. In addition, respondents commented that the current structure of the hoe requires a heavier handle to manage the blade's weight. The connector would ensure that lighter handles are used which would be more ergonomically suited to women farmers.

Although the researchers engaged local tool makers and engineers at the research institutions to assess the viability of the proposed tool designs from an engineering perspective, the women innovator groups were central to the tool development process. Below are the findings for each stage of the co-design and prototyping process completed.

Land Clearing 2D-Designs

Suggestions from women farmers included the need to improve the ergonomics, make it lighter and enable them to complete the task faster. For most of the innovator groups, the main suggestions were to make the blade and handle longer and to shorten and stabilize the handles. The groups opted for two different blade designs that were tested for further refinement and prototyping. The results in the tables below shows; 1) the site-specific preferred average dimensions of improved land clearing tools and 2) the average dimensions used to produce the prototypes for field testing. The final specifications were then translated 2D designs.

Table 4-3: Average Site-Specific Dimensions Preferred in The Improved Land Clearing Hoe

Land Clearing Hoe Specifications (in CM)	Location	Mean Dimensions from Groups	Total Averag	P.value (0.05)
Handle Length	Kabudula	79.214	82.107	1.334
	Nkhamenya	85.000		
Handle Diameter	Kabudula	3.243	3.193	1.570
	Nkhamenya	3.143		
Handle Weight	Kabudula	.61250	.673	1.451
	Nkhamenya	.79250		
Blade Length	Kabudula	13.857	11.893	1.011
	Nkhamenya	9.929		
Blade Width	Kabudula	17.114	17.200	1.655
	Nkhamenya	17.286		
Blade Pin height	Kabudula	16.700	16.888	1.936
	Nkhamenya	17.200		
Blade Weight	Kabudula	.75875	.725	1.365
	Nkhamenya	.65750		
Blade-Handle Angle	Kabudula	77.286	75.091	1.252
	Nkhamenya	71.250		

Table 4.7.3.1-3: Final Land Clearing Tool Design Specifications

Tool Specifications	Curved Blade	Grated Blade
Length of Blade	18cm	25cm (including spacing)
Width of Blade	14.5cm	13cm (including spacing)
Spaces Between Windows (Length)	N/A	6cm
Spaces Between Windows (Width)	N/A	5cm
Blade to Handle Connector Angle	75 degrees	85 degrees
Handle Connector Length	8cm	8cm
Handle Connector Diameter	4cm	4cm

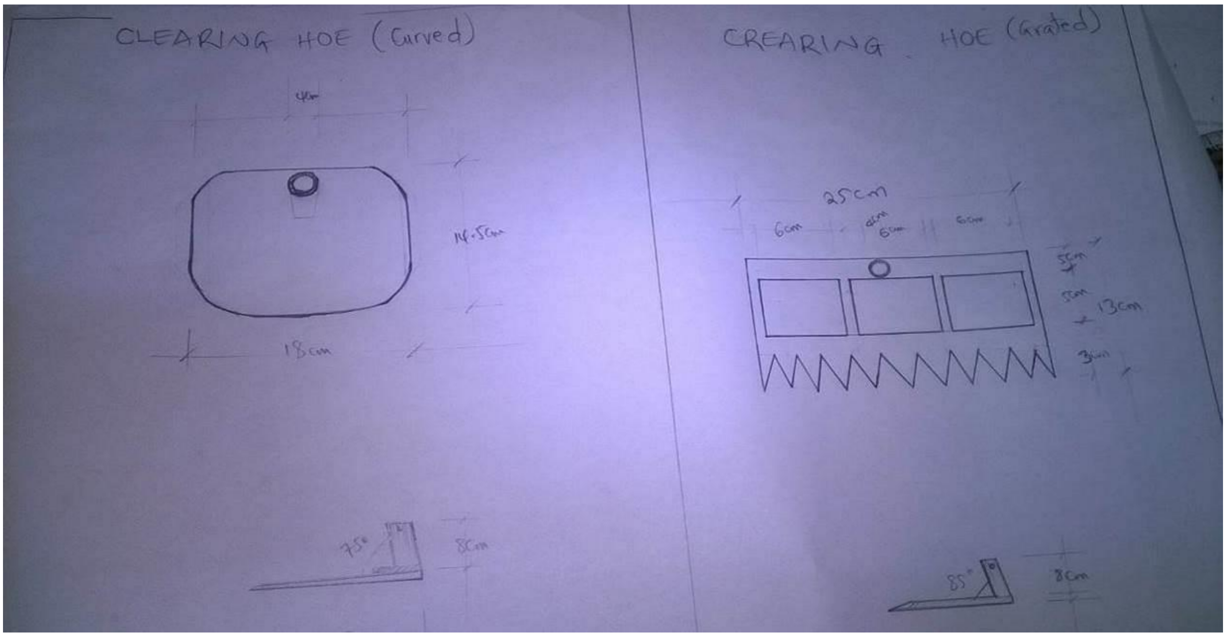


Figure 4-2: Land clearing 2D-design

Ridging 2D-Designs Proposed by Women Farmers

Key refinements that were suggested by the women smallholder farmers to the existing ridging and banking hoe included*: 1) use of stronger metal for durability, 2) a stabilized handle to blade* connection *and 3) longer/shorter handles depending on the research site.* The results in the tables below show the site-specific preferred average dimensions of improved ridging and banking tool and the dimensions used to produce the prototypes for field testing. The final specifications were then translated 2D designs.

Table 4-4: Average Dimensions Preferred in Improved Ridging and Banking Hoe

Ridging Hoe Specifications (in CM)	Location	Mean Dimensions from Groups	Total Average	P.value
Handle Length	Kabudula	78.500	84.125	1.017
	Nkhamenya	88.143		
Handle Diameter	Kabudula	3.540	3.426	1.172
	Nkhamenya	3.338		
Weight	Kabudula	.82929	.917	1.006
	Nkhamenya	1.00500		
Blade Length	Kabudula	22.490	22.322	1.662
	Nkhamenya	22.192		
Blade Width	Kabudula	18.010	18.113	1.423
	Nkhamenya	18.192		
Pin Height	Kabudula	14.875	15.938	1.616
	Nkhamenya	17.000		
Weight	Kabudula	.99857	1.060	1.185
	Nkhamenya	1.12214		
Blade-Handle Angle	Kabudula	69.444	74.684	1.202
	Nkhamenya	79.400		
	Nkhamenya	1.000		

Table 4-5: Final Banking and Ridging Tool Design Specifications

Tool Specifications	**Ridging Hoe**
Length of Blade	17.5cm
Width of Blade	25cm
Blade to Handle Connector Angle	65 degrees
Handle Connector Length	8cm
Handle Connector Diameter	4cm

Planting 2D-Designs Proposed by Women Farmers

For the planting activity, farmers indicated that hands, old small blades, legs, hoe handles and sticks were the commonly used tools. The table below lists the tools and planting methods that are common with respect to the number of respondents using them at the time of the research. The results show; 1) the list of planting tools to be improved, 2) the two tool designs proposed by the innovator, 3) the site-specific preferred average dimensions of the improved 3-blade planter and the Sasakawa hoe designs and 4) the dimensions used to produce the prototypes for final field testing.

Table 4-6: Suggested tool refinements to 3-Blade Planter Design

Refinements Proposed to 1st Design (3-blade Planter)	Number of Respondents
None	33 (52%)
Somebody should be putting the seed	20 (31%)
Can only be used on wet ridges	4 (6%)
Make it lighter	2 (3%)
Use stronger metal for blade	2 (3%)
Increase the blade length	1 (1%)
Reduce blade diameter	1 (1%)
Total	**63**

Table 4-7: Average Dimensions Preferred in Improved Planting Hoe

Planting Hoe characteristics	Location	Mean	Total Average	Sig.
Handle Length	Kabudula	61.000	61.000	2.000
	Nkhamenya	61.000		
Handle Diameter	Kabudula	2.953	2.969	1.877
	Nkhamenya	2.986		
Handle Weight	Kabudula	.41357	.491	1.301
	Nkhamenya	.59900		
Blade Length	Kabudula	13.833	11.627	1.002
	Nkhamenya	9.420		
Blade Width	Kabudula	9.767	11.523	1.034
	Nkhamenya	13.280		
Blade Pin Height	Kabudula	10.880	12.519	1.236
	Nkhamenya	15.250		
Blade Weight	Kabudula	.30643	.379	1.150
	Nkhamenya	.48000		
Blade-Handle Angle	Kabudula	85.357	82.083	1.585
	Nkhamenya	77.500		
	Nkhamenya	4.167		

Table 4-8: Final Planting Tool Designs and Specifications

Tool Specifications	3-Blade Planter	1-Seed Sasakawa Planter
Length of Whole Blade	72cm (including blades)	9cm
Width of Whole Blade	14cm (including handle)	7.5cm
Length of individual blades	5cm	N/A
Width of individual blades	6cm	N/A
Blade to Handle Connector Angle	85 degrees	75 degrees
Handle Connector Length	7cm	7cm
Handle Connector Diameter	4cm	4cm
Spacer blade	3cm	N/A

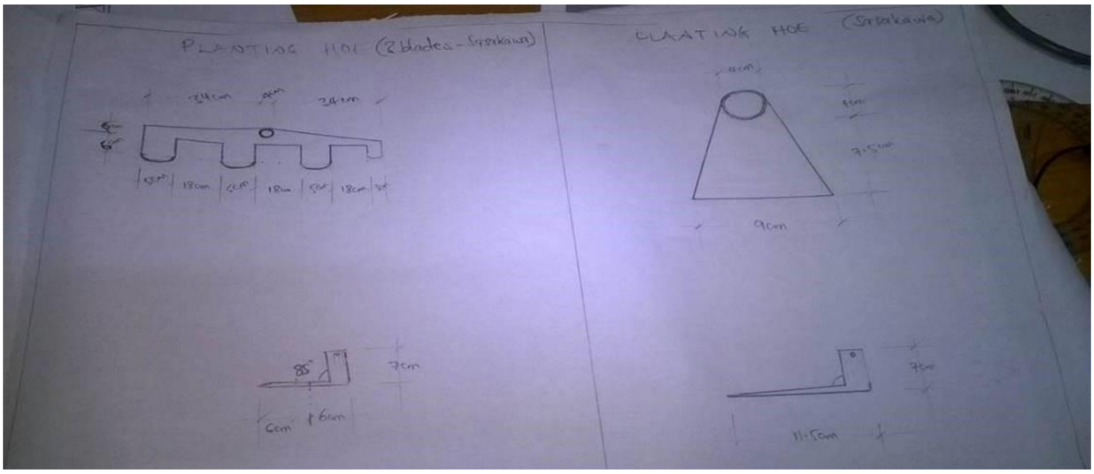


Figure 4-3: Planting 2D-Designs: 3Blade Planter and Sasakawa 1-seed Hoe

Women farmers' Proposed Weeding 2D-Designs

The most commonly used tool for weeding was a traditional hoe with roughly 3-5 years of wear and tear (as per the women farmers). The ideas on how to improve the hoe for weeding led to the development of customized weeding hoes i.e. the Straight Edge Blade and the Grated/Flat Blade.

Table 4-9: Suggested Refinements for the Weeding Hoes

Refinements	**Frequency**	**Percent**
None	27	31%
Sharpen (applies to both designs)	7	17%
Make it flat (applies to both designs)	3	7%
Add some weight (applies to both designs)	2	5%
Bring the grates closer (applies to grated design)	2	5%
Has to be round, remove grates	2	5%
Make it more stable (applies to grated design)	2	5%
Reduce the angling (applies to grated design)	2	5%
Use a stronger metal (applies to both designs)	2	5%
Increase the angling (applies to straight edge design)	1	2%
Make it wider, heavier (applies to straight edge design)	1	2%
Make the blade longer (applies to straight edge design)	2	5%
Make handle shorter (applies to straight edge design)	1	2%
Tighten bot and nut (applies to both designs)	1	2%
Widen the blade (applies to straight edge design)	1	2%
Total	**42**	**100%**

Table 4-10: Average Dimensions Preferred for the Improved Weeding Hoe

Weeding Hoe characteristic	Location	Mean	Total Average	Sig.
Handle Length (cm)	Kabudula	79.208	85.940	1.094
	Nkhamenya	92.154		
Handle Diameter (cm)	Kabudula	3.058	3.080	1.789
	Nkhamenya	3.100		
Handle Weight	Kabudula	.69571	.733	1.489
	Nkhamenya	.78500		
Blade Length	Kabudula	13.625	13.360	1.663
	Nkhamenya	13.115		
Blade Width	Kabudula	17.833	17.620	1.727
	Nkhamenya	17.423		
Blade Pin height	Kabudula	17.438	17.931	1.751
	Nkhamenya	18.720		
Blade Weight	Kabudula	.61214	.646	1.580
	Nkhamenya	.69300		
Blade-Handle Angle	Kabudula	75.091	74.050	1.719
	Nkhamenya	72.778		
	Nkhamenya	3.000		

Table 4-11: Final Weeding Tool Designs and Specifications

Tool Specifications	Straight Edge Blade	Grated/Flat Blade
Length of Blade	15cm	25cm (including spacing)
Width of Blade	16cm (including spacing)	13cm (including spacing)
Spaces Between Windows (Length)	N/A	6cm
Spaces Between Windows (Width)	N/A	5cm
Blade to Handle Connector Angle	75 degrees	85 degrees
Handle Connector Length	8cm	8cm
Handle Connector Diameter	4cm	4cm

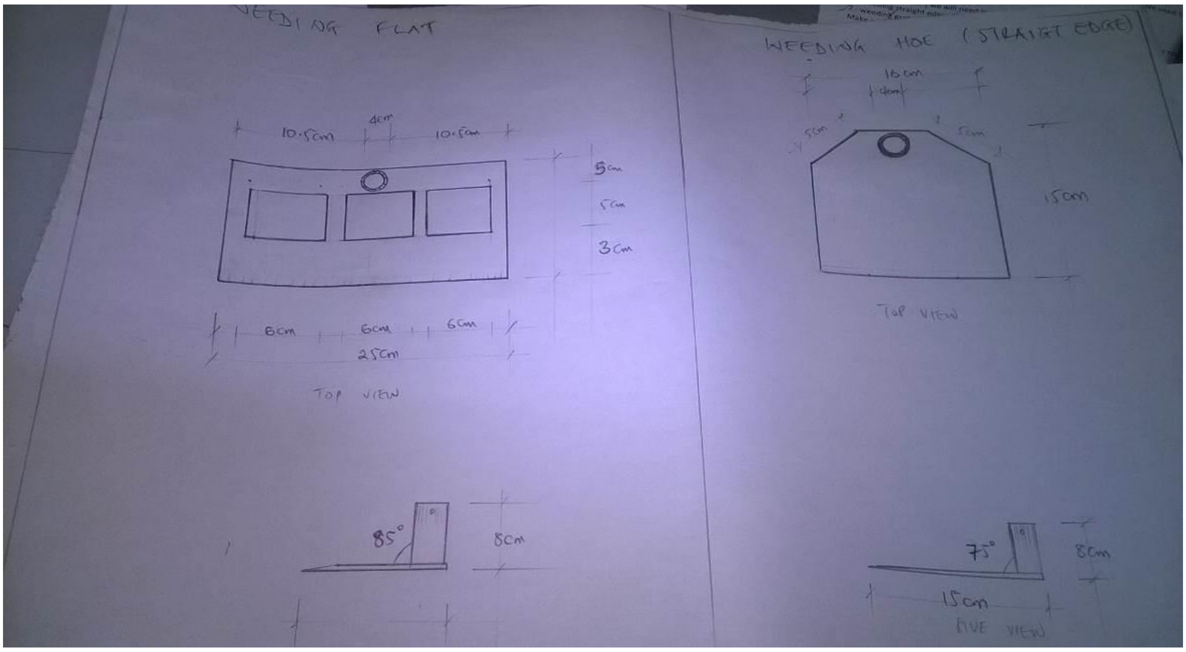


Figure 4-4: Weeding 2D-Designs

4.4.3 Women farmers Design Concepts for Post-Harvest Season Tools

The women innovator groups discussed several options for technology designs to produce tools for the identified labor-intensive post-harvest tasks. The smallholder farmers indicated that they did not own or rent any post-harvest machines and as a result, they typically use their hands or sticks for most post-harvest activities. This confirmed previous research (Pingali, 2007) that observed low adoption of mechanized technologies in sub-Saharan African countries including Malawi. Post-harvest activities that were identified as labor-intensive were also rated as extremely time-consuming while existing post-harvest management methods were rated as least effective. The innovator groups expressed the highest need for improved technologies for post-harvest tasks to save significant time and energy. These groups also identified the income-generating opportunity these machines would bring them as the groups stated that they could use these post-harvest technologies to generate income from nearby communities by running a pay-per use service.

During the design phase, the innovator groups were shown existing post-harvest technologies that are in use in rural and semi-urban centers in Malawi and around neighboring countries. These included various types of maize grinders, winnowers, threshers, among others. Where the physical tools were unavailable, the research provided pictures to the innovator groups that served as a starting point for the design sessions. Based on these exposure sessions, the innovator groups conceptualized their preferred designs for improved machines that are affordable/accessible to the farmers. Once the initial designs were made, different refinement suggestions were also made by the women farmers to further customize them for improved performance. The tables below list a number of refinements suggested by the women innovator groups to be made to the existing post-harvest methods .

Table 4-12: Existing Tools for Post-Harvest Operations

Tool Preferences	Responses
Hands	43%
Mortar & pestle	29%
Winnower	16%
Maize grinder	5%
Maize Sheller	1%
Groundnut Sheller	3%

Table 4-13: Suggested Improvements to Post-harvest Designs - Initial Prototype

Refinements	Use Hands	Mortar & Pestle	Single Winnower	Maize Grinder	Maize Sheller	Groundnut Sheller & Winnower
Adjust the Blades				X		X
Cover the Flywheel			X			X
Fix the Handle		X				
Make It Softer		X	X	X	X	X
None	X	X	X	X	X	X
Interchangeable Sieve				X		
Reduce the Size			X	X		
Stabilize It		X	X			X
More Upright			X	X		X
Change Sieve			X	X		X

After getting the ideas from the smallholder women farmers, the ideas from the innovator groups were compiled and interpreted into conceptual tool designs. 2D sketches were made (see pictures above) and sizes for the parts of the tools conceived. The sketches were taken to the welder to verify the on the ability of the concepts to be worked on via the welding route. The final designs and dimensions agreed did not alter the original concepts suggested by the women farmers. The designs and concepts were then 3D modelled in a CAD Software (123Design by Autodesk). The 3D models were printed to have a physical presentation of the tool designs. However, because the tools were too big to be printed in 1 go on the 3D printer, they were printed in parts which represented the complete design of the tools.

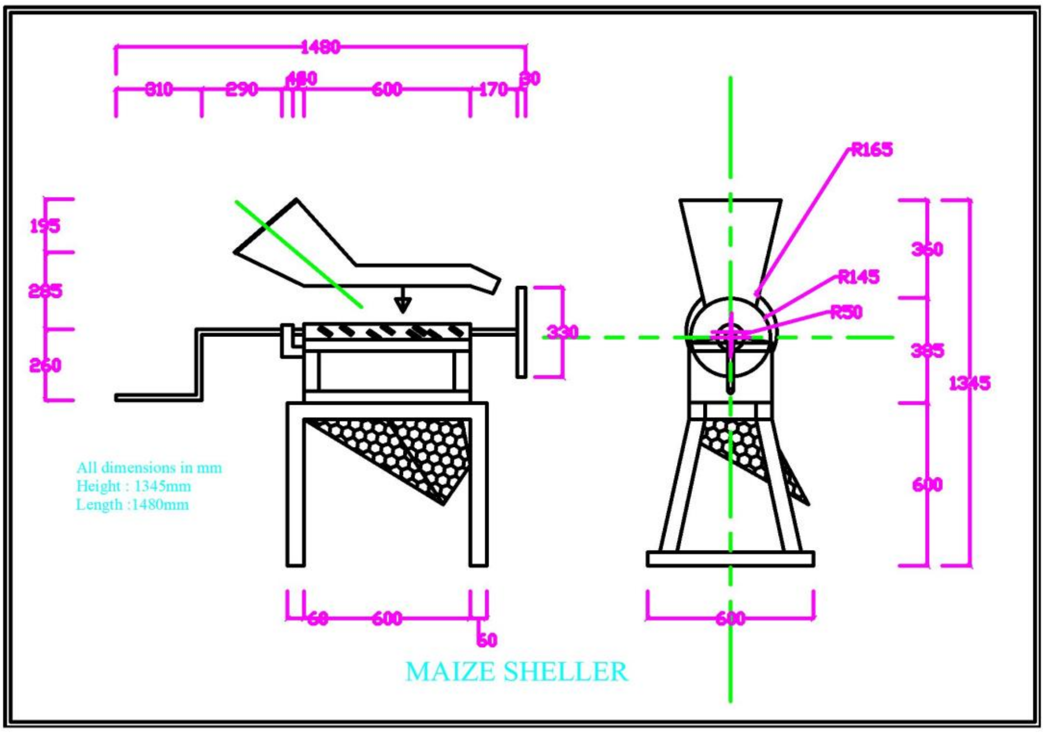


Figure 4-5: Maize Sheller 2D Design

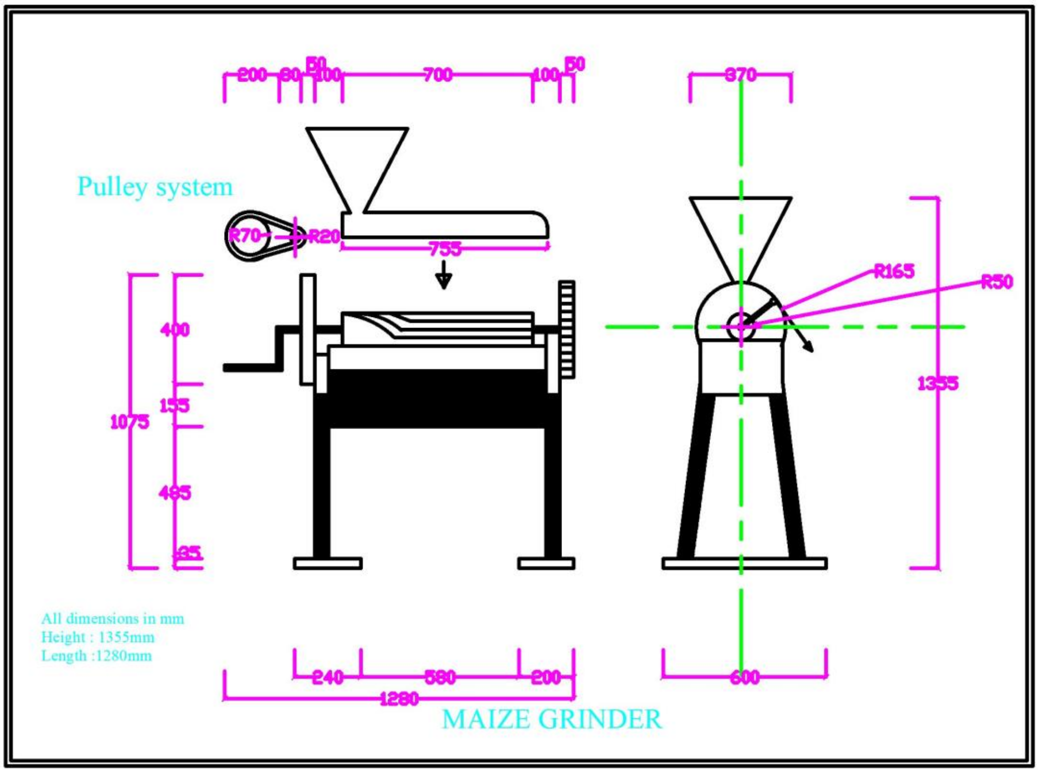


Figure 4-6: Maize Grinder 2D Design

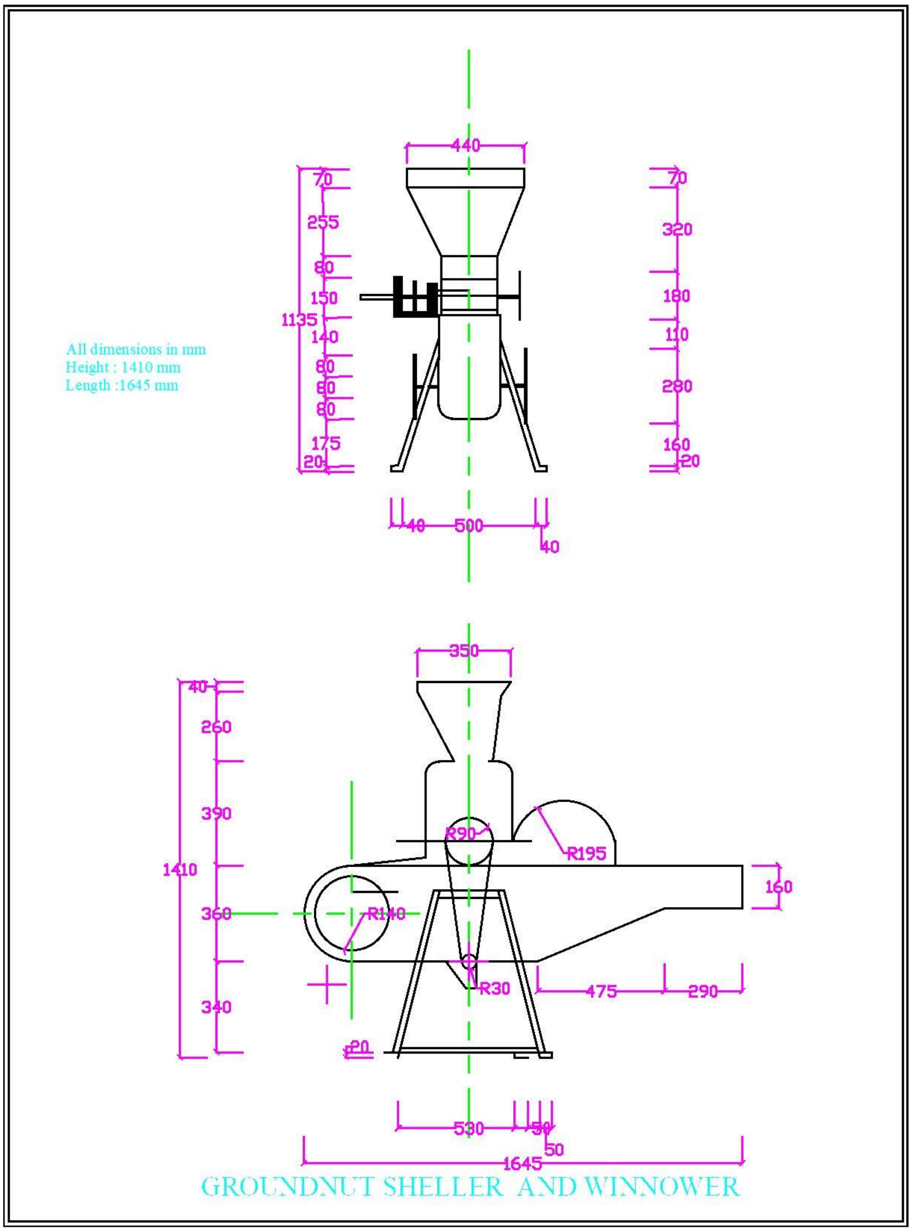


Figure 4-7: 2in1 Groundnut Sheller and Winnower Design

The 3d printed pieces were also taken to the welder to be used as samples during welding and assembly. The first tool prototypes were tested at the workshop with maize and groundnut grains to assess their performance. From the assessment after testing the tools, a decision was made to take them for further testing in a farm setting with the farmers. The tools were assessed by the farmers in terms of ergonomics (height, length, handling etc.), performance against using hands, quality of the produced seed from the machine and the time savings. The farmers made recommendations on which modifications they needed and the tools were then returned to the welder for further adjustments. Further recommendation could be made by the farmers for further adjustments until the tools get as close to perfection as possible.

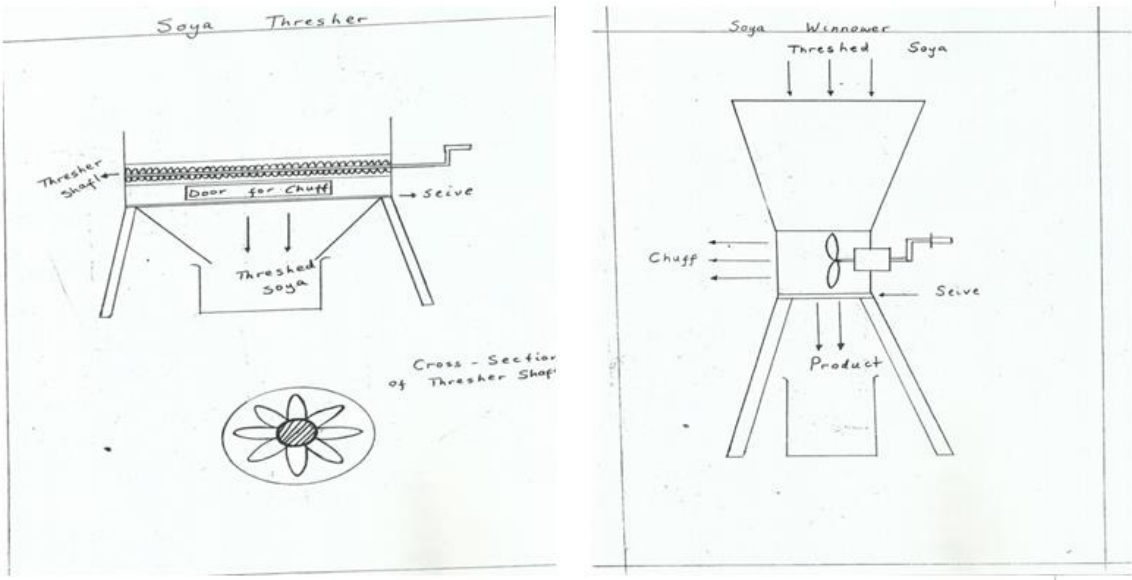


Figure 4-8: Soya Threshing and Winnower Design

As there were very little resources available, the test for the soya threshing and winnowing prototype was only conducted in one site, with 3 women innovator groups. This involved testing of the soya bean thresher (farmer designed prototype) in comparison to existing soya bean threshing methods (using poles to hit the sacks of harvested soya bean pods).

4.4.4 Prototype Development for Cultivation and Post-Harvest Tools

The development of new tools relied heavily on the visual aids of the tools that were used to simply the prototyping process to save manufacturing time and resources. This was made possible by rapidly prototyping the designs ideas using 3 options. The tools were first represented by 3D micro prototypes which were then used for reference purposes for the following stage of rapid prototyping that was completed to scale for each viable design.

3D Printing Micro-Prototyping of Labour Saving Tool Designs

3D printing refers to a process where 3-dimensional (3D) physical objects are created from computer models made in Computer Aided Design software (CAD) (Ishengoma and Mtaho, 2014). This method provides the power to convert a 2-dimensional digital design into 3D objects. The 3D printing technique has been applied in a wide range of fields such as medicine, agriculture and others (Yang et al., 2015, Ishengoma and Mtaho, 2014).

For this research, 3D micro-prototypes were created using the MakerBot industries desktop printer that was donated to the 3D4Agdev research. The 3D printing process was completed despite many electricity supply disruptions, a challenge that has been previously reported by other researchers regarding similar investigations on technologies (Taulo et al., 2015). Printed 3D micro-prototypes were then presented to local artisans who produced welded prototypes using locally available scrap metal.

The use of this rapid prototyping technique significantly shortened the manufacturing process since valuable resources weren't wasted producing samples. Resources were frugally used as the additive 3D manufacturing process does not waste raw materials and uses the exact amount of biodegradable plastic to produce the 3D objects.

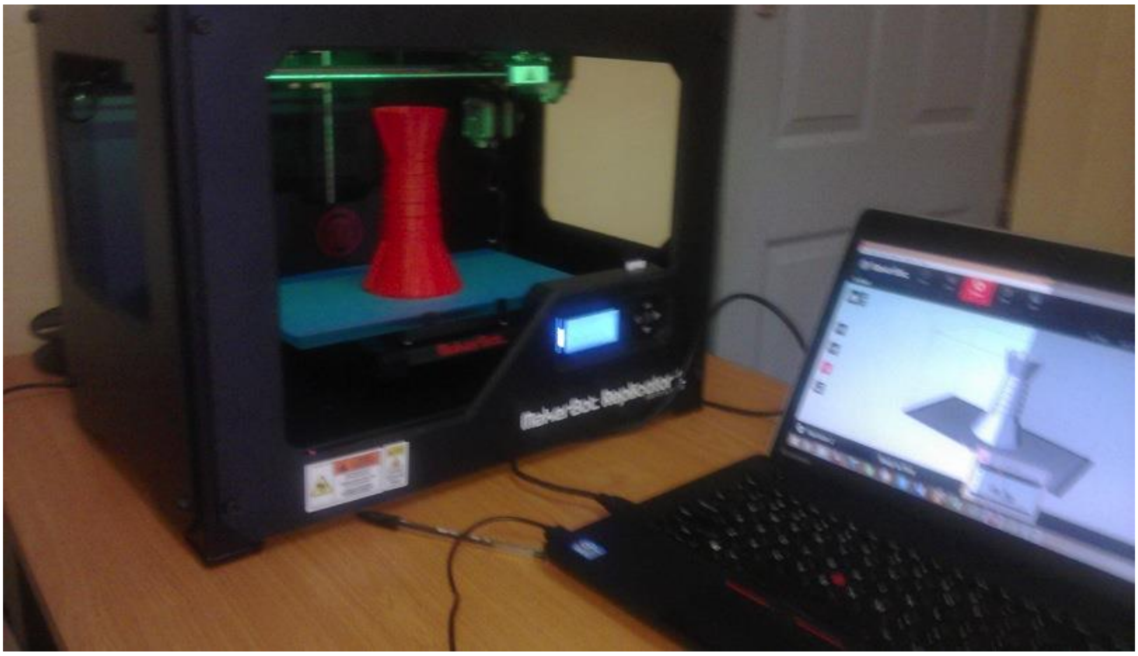


Figure 4-9: A computer connected to a 3D printer-Chitedze Research Station.

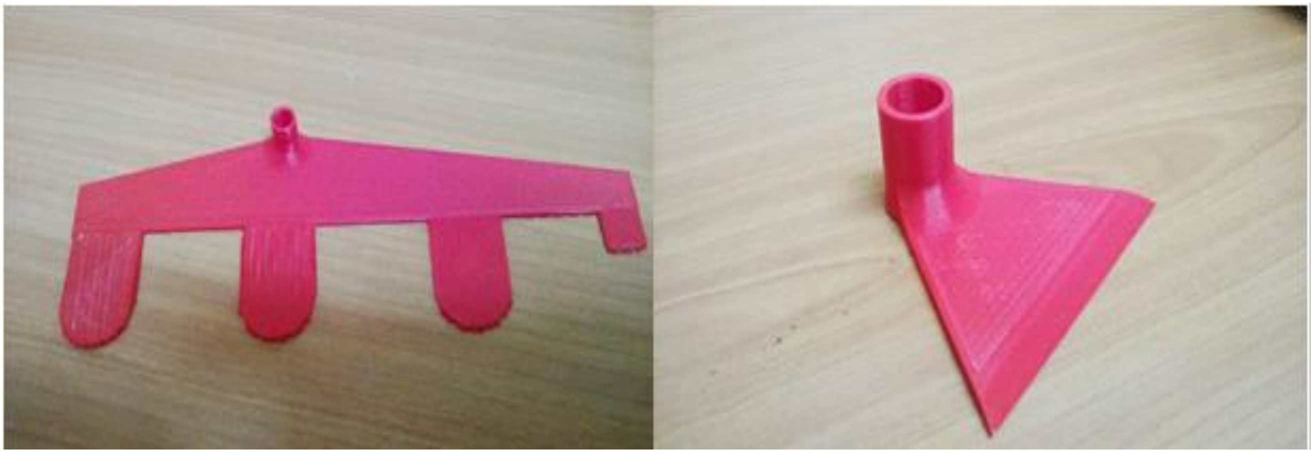


Figure 4-10: 3-Blade Planter & 1-Seed Sasakawa 3D Printed Micro Prototypes.

Figure 4-11: Land Clearing:3D Printed Micro Prototypes.

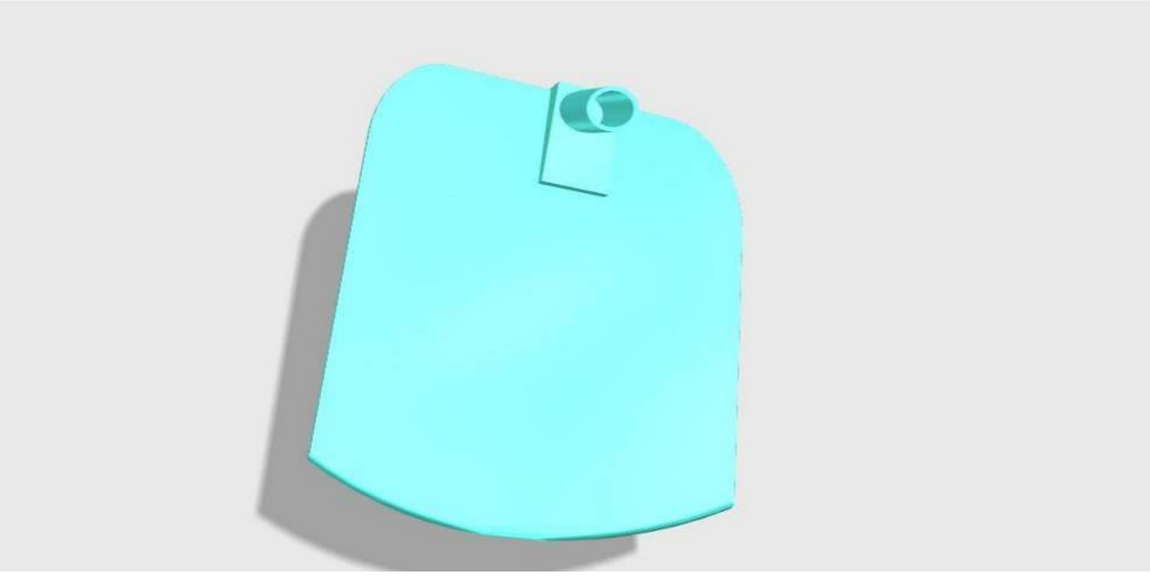


Figure 4-12: Ridging Hoe with Blade Connector: 3D Render of Designed Prototype.

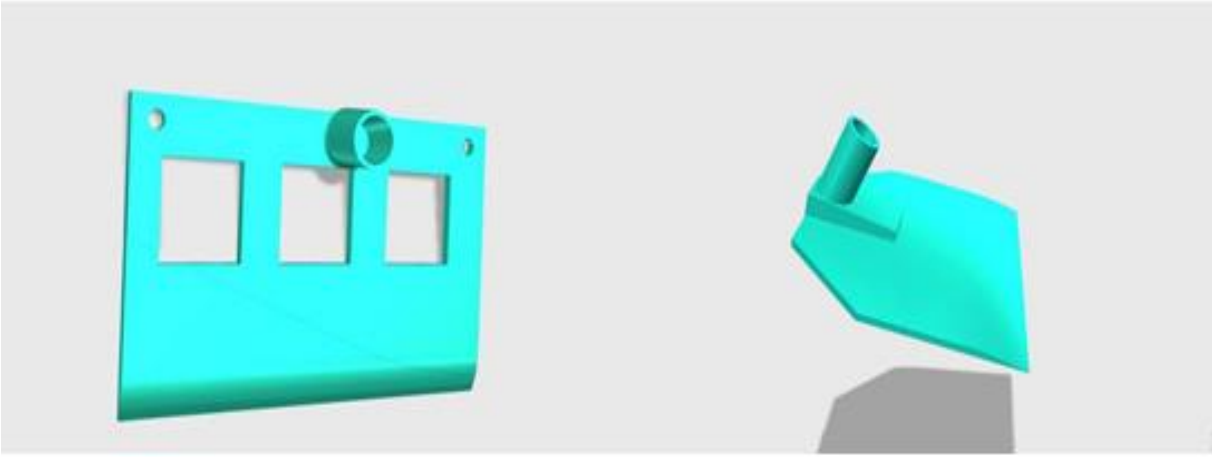


Figure 4-13: 3D Renders of Weeding Prototypes

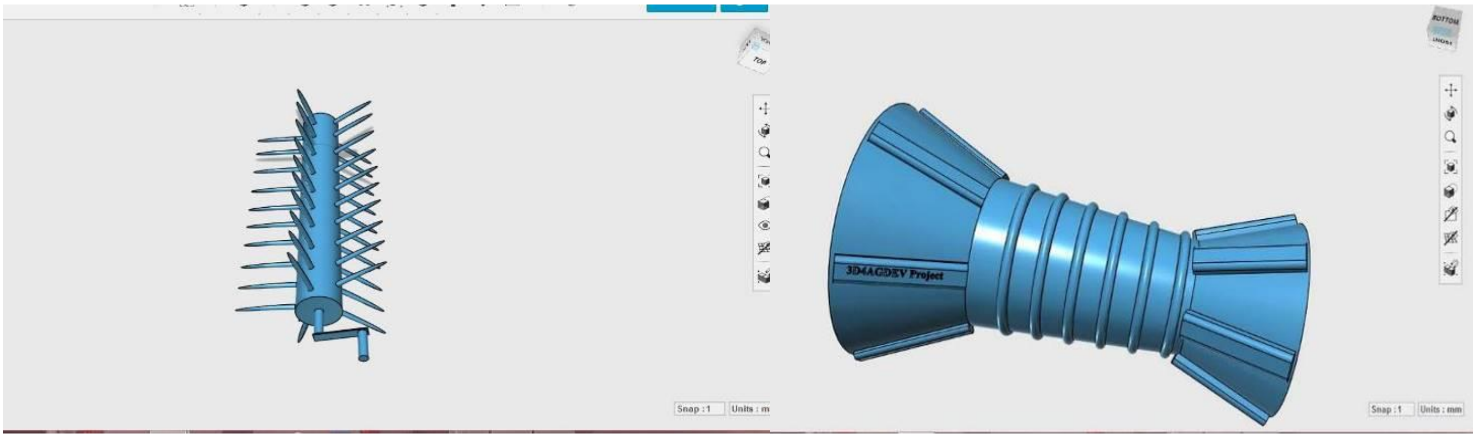


Figure 4-14: 3D Render of Designed Maize Sheller Blade & Hand-Held Maize Sheller

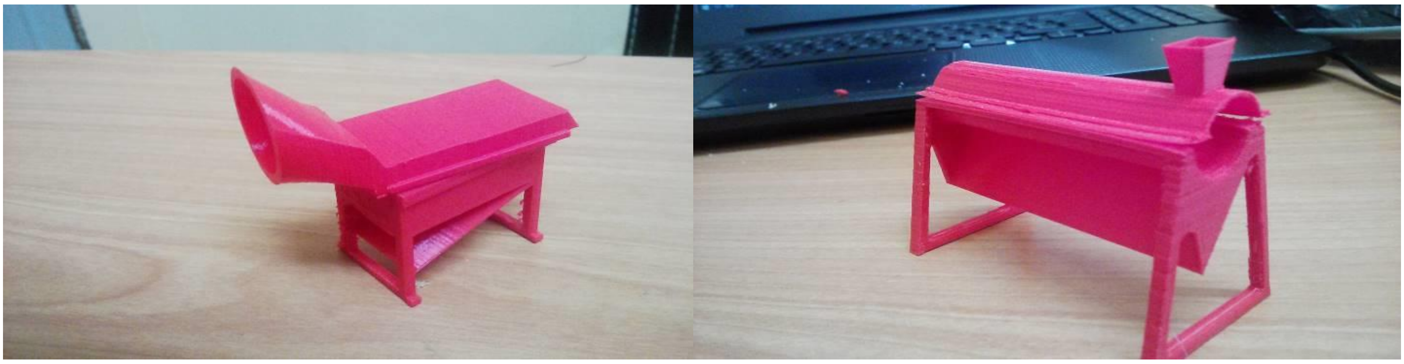


Figure 4-15: Maize Sheller and Maize Grinder 3D Printed Frames

Local Arc Welding production of prototype labour-saving Cultivation Tools

The research engaged local welding expertise and identified artisans who produced the welded prototypes to be tested by the women innovator groups. The below prototypes were produced to scale using the 3D printed samples. The tools were produced using locally available scrap metal and flat sheets that the research sourced from scrap metal vendors and welders around the industrial areas. As the research was resource-limited, other materials e.g. flatsheets, were procured at the cheapest prices available to produce the tools with the lowest unit price possible.

Figure 4-16: Weeding Wide-Blade Hoe & Planting Three-Poker Planter

Figure 4-17: Sasakawa 1-Seed Planting Hoe & Land Clearing Curved-Blade Hoe

Figure 4-18: Three-Blade Planter and Two-Blade Planter

Local Arc Welding for Post-Harvest Tools to be Prototyped

The women farmers’ innovator groups were engaged in creative design sessions in addition to the focus group discussions. Each of the innovator groups conceptualized innovations for the labour intensive tasks they highlighted in chapter 3, page 68 and chapter 4, page 91. There were 5 new prototypes co-designed with women smallholder farmer innovator groups that were customized to address the identified labour intensive tasks:

a) *Groundnut sheller and winnower (2 in 1),*
b) *Maize Sheller,*
c) *Maize Grinder,*
d) *Soya and Bean Thresher and*
e) *Soya and Bean Winnower.*

Figure 25a: Prototypes (scrap metal): 1) Maize Sheller, 2) Groundnut Sheller & Winnower, 3) Maize Grinder

Metal Casting Prototyping of Labour-Saving Cultivation Tools

Once the welded prototypes were produced for testing and findings known, it was determined feasible to compare these findings with those of tools produced with the 2rd prototyping option-metal casting. Based on the same results on the 2D tool design prototypes, the 2nd rapid prototyping phase was completed through metal casting. The metal cast prototypes were produced with more durable quality metal (hardened steel) and with refined dimensions (height, weight, thickness of blades, and location of connector among others), which were based on results from the 1st on-farm testing conducted using welded prototypes (scrap metal).

Figure 4-19b Blade Planter Mould and Sample of Metal Cast Prototypes

Figure 4-20: Weeding and Clearing Prototypes and metal cast Mould

Figure 4-21: Sasakawa Planting Hoe Mould and Metal Cast Prototypes

Metal Cast Prototyping of Post-Harvest Labour-Saving Tools

The results from the phase 1 on-farm testing demonstrated significant time savings for the post-harvest innovations co-designed by women innovator groups. Metal casting was not therefore explored for these tools as the welding option was more cost-effective and the quality was reliable.

4.5. Discussion and Conclusions

Throughout all the co-design processes, the innovative thinking capacity of the female farmers was tested and proven. To ensure that innovator groups were happy with their designs and also that local artisans had a visual representation of the tools as expressed by the end-users (Gupta et al., 1997), the first process in the development of the tools was to develop 3D micro prototypes. Local artisans were engaged who sourced locally available scrap metal to develop the prototypes. To further compare the durability and weight of the tools, the study decided to improve the tools further by developing metal cast tools. This idea was supported by findings of (Klobčar et al., 2007) who reported superior resistance in metal cast tools than welded tools. The research investigated the hypothesis and the findings are detailed in chapter 5 (page 124) of this thesis. Based on the results of this co-design process, it can be concluded that the selected female smallholder farmers were successfully tested to be innovative as this group of "best-bet innovators" successfully co-designed tools for their labor-intensive agricultural tasks and were key players in the final production of the new and improved tools. At this stage of the research, it was noted that through participatory approach and given the existence of enabling creative spaces, selected cohorts of women smallholder farmers with innovative capabilities can and should be engaged to successfully steer the process to develop tool innovations that are useful in addressing the labour constraints of their farming activities.

The findings enabled the research to make the argument that for technologies to address target groups' needs/demands, women smallholder farmers need to be included and that their ideas must be taken into consideration during the research and development process for each agricultural technology to be introduced into their markets. Women smallholders and local tool producers must be better equipped with knowledge and skills on how to improve their agri-tools and implements to incorporate time and labour saving strategies. The next chapter provides details of the on-farm time differential trials that were conducted to compare the prototypes produced in this chapter to the existing tools found in the researched areas of rural Malawi.

5. CHAPTER 5: PARTICIPATORY ON-FARM PROTOTYPE ASSESSMENT

As outlined in chapter 4, women smallholder farmers have demonstrated their capacity to identify innovative ideas for tools tailored to labor-intensive activities during their farming cycle. Using the tools co-designed and now prototyped, the next step was to conduct on-farm trials of existing hand-held agricultural tools and the newly produced prototypes to compare the time taken to complete the tasks. This chapter provides a detailed review of the approach taken during the on-farm trials of tools with the selected women innovator groups in Malawi.

5.1. Research Objectives

- *To investigate whether the co-designed innovative technologies prototyped using local arc welding demonstrated any time savings with respect to existing technologies during the on-farm cultivation trials.*
- *To assess whether the co-designed innovative technologies prototyped using metal casting demonstrated any time savings with respect to existing technologies during the on-farm cultivation trials.*
- *To assess user preferences for the tools tested during the participatory on-farm trials with women smallholder farmers who are members of the 3D4AgDev innovator groups described in earlier chapters of this thesis.*

5.2. Research Methodology

As detailed in chapter 4, the research showed evidence that women smallholder farmers can be engaged in the participatory process to co-design of labour saving agricultural tools. This chapter outlines the protocol, rationale, methodology and results of the participatory technology evaluations that were carried out using field tests to identify the most time-saving tools. It compares the results of the on-farm trials to compare existing tools to new prototypes produced using welding and metal casting.

It also highlights the role that women smallholder farmers played in the on-farm testing of the new co-designed prototypes and existing tools. Key informant interviews collected data from the women farmers on their tool preferences that were analyzed and presented in the results sections.

5.2.1 Testing Protocols

A robust set of protocols was developed for the field testing to ensure that reliable data was generated to develop an evidence-base for each tool. The participatory technology evaluations were organized based on the season during which the tool is used. The innovator groups were engaged to identify appropriate farm land and test the existing tools and new prototypes. The results of the participatory on-farm field trials and feedback from the women farmers would enable comparisons to be made between the two sets of tools to select the best time saving tools. The research was designed to allow open and enabling creative field testing spaces, borrowing elements of the IDEO Human Centers design process as described by (IDEO.org, 2015), where the women farmer groups focused on what they considered to be labour intensive and tested the tools for their specific tasks. Each innovator group participated in the field-testing exercises for both the cultivation and post-harvest periods and ranked the tools for effectiveness and time savings.

The testing sessions were conducted at central meeting locations with the women farmer innovator groups that were equally represented to enhance inter-group learning.

5.2.2 Testing Parameters

Cultivation Tools Versus Existing Traditional Tools

Each tool was assessed based on these parameters and the results for all the tested tools were then compared for each group and similarities were grouped together for consensus building:

- *Time taken per tool*
- *Choice of preferred Handles*

The cultivation tools testing sessions were conducted for the identified labor-intensive tasks i.e. land clearing, ridging, planting and weeding trials. The land identified was demarcated into individual activity trial plots where each user was allocated 3 ridges/furrows to test the new tools on and this was repeated with the existing tools. Each ridge was measured at 20 meters long and the space from one ridge to the next was measured at 0.75 meters wide. For each trial conducted, the farmers were selected randomly from the various women innovator groups. Participants were required to perform 4 trials: *clear a portion of land and collect the clearings, make ridges, plant seeds and weed the plots.* Each testing participant would conduct the same trial with the existing tools or using the existing method and would repeat the task using the new prototypes assigned for the test. The time taken for each test was then recorded and analyzed.

<u>*Constant Factors During Trials*</u>

i. **Land used:** All tool trials were conducted under the same land conditions.

ii. **End-users:** For each trial, there were 6 women farmers testing the tools i.e. 3 users testing the existing tools and 3 users testing the new co-designed prototypes. The researchers then switched the tools to ensure that the same women would conduct the tests again i.e. the same user testing an existing tool and a new tool. For each tool prototype, the tool was produced in triples as the research was also testing the user preferences for tool handles considering the cultural preferences of the 2 sites. The tool handles were produced in three different sizes described as “long” (1.5 meters), “medium” (1 meter) and “short” (0.5 meters). Therefore, each user tested the existing tools and new co-designed prototypes two times each**.**

iii. **Farmers Diet:** Before conducting the trials, data on the farmers’ breakfast composition was captured. As most farmers typically did not have breakfast, data on the previous day’s last meal was also captured to have estimate their energy levels before the tests.

iv. **Inputs for On-Farm Trials:** All tools were labelled during the testing sessions and the end-users were allowed time to familiarize themselves with the new tools. The seeds required for planting and grain required for the testing of the existing tools were available to test the new prototypes.

Post-Harvest Prototypes Versus Existing Methods

Each prototype was tested in comparison to the existing tools and methods the women farmers presently use. The results for all the tested tools were then compared for each group and similarities were grouped together for consensus building the time taken per tool to complete the labor-intensive activity.

Maize Shelling

The smallholder women farmer innovators that were engaged in the tool testing sessions to define the methods they typically use to shell their maize. Most respondents stated that they shell by hand or by rubbing the full maize cob against an empty cob. The women were asked to shell maize from 1kg of maize cobs which is approximately 6-7 maize cobs per trial. The timer was set to capture the time taken to shell the maize from 1kg of maize cobs by hand or using an empty cob. The times recorded were then compared to the time taken to shell the same quantity of maize using the new women farmer co-designed maize sheller. The smallholder women farmer innovators that were engaged in the tool testing sessions typically have farming plot sizes of 0.2 to 2 hectares (ha.) producing yields of approximately 67 bags of maize cobs per hectare. One bag typically weighs 50kgs. One kg represents approximately 6-7 maize cobs.

Maize Grinding

The smallholder women farmer innovators also highlighted the existing methods they typically use to grind their maize. The respondents indicated that most of them use the pestle and mortar to grind maize.

The women testers were asked to grind maize from 1kg of maize cobs which is approximately 6-7 maize cobs per trial. The timer was set to capture the time taken to shell the maize from 1kg of maize cobs using the pestle and mortars which the smallholder women farmers provided. These times taken were then compared to the time taken to shell the same quantity of maize using the women farmer co-designed maize sheller provided by the research.

Groundnut Shelling and Winnowing

Women smallholder farmer innovators indicated that they typically use their hands to shell groundnuts. The innovator group participants were engaged to test the existing method against the new co-designed prototypes. They were asked to shell 1kg of groundnuts and the timer was set to capture the time taken to complete this task by hand. The times taken were then compared to the time taken to shell the same quantity of maize using the women farmer co-designed groundnut sheller provided by the research.

The women smallholder farmers were also asked to identify what they use to winnow and clean the shelled groundnuts. The women answered that they typically use a winnower made from local bamboo or other soft malleable materials. The group of women who volunteered for the groundnut shelling testing session were then asked to winnow the groundnuts they shelled by hand. This time was added to the time taken to shell the groundnuts by hand. This total time was then compared to the time taken to shell and winnow the same quantity of groundnuts using the 2in1 groundnut sheller and winnower co-designed prototype. The smallholder women farmer innovators that tested the groundnut tools typically have plot with yields of 50-60 bags of unshelled groundnuts per hectare. Each of these bags typically weighs 50kg.

Soya Threshing and Winnowing

The women farmers who participated in the tool testing sessions indicated that they typically place the harvested soya pods on sacks and cover them. They then source poles which they use to hit the sacks to break open the soya bean pods and release the grain. Due to resource limitations, these on-farm trials were not conducted with all the women smallholder innovator groups that co-designed the prototype. However, on a one-day prototype showcasing field day, the prototype was tested with three groups in one of the research sites. The women farmers were asked to test the soya thresher and winnower using one kg of unthreshed soya bean pods. The time taken was compared to the existing method already identified by the women smallholder farmers.

5.3. Data Collection Techniques and Methodology

A mixed methods approach was applied to capture both qualitative and quantitative data during field tool trials. The tool trials data was collected through recordings of time taken when using existing and new prototyped tools. Field observations of women smallholders during the tool's trials enabled the observation of the participants in their natural environment.

5.3.1 Key Informant Interviews (KIIs)

KIIs were conducted at the beginning and end of each field-test to collect feedback to be incorporated with the time differential results. For each trial session, each user completed a questionnaire to provide feedback on their perception of the tool before testing it as well as after completing the tool trial. Participants were asked to provide their preferred tool dimensions including handle length and weight, blade length, width and weight as well as the handle to blade angles. Farmers also ranked the tested tools for ease of use, time taken and overall ergonomic suitability of the tool. In addition, they were asked to share their ideas how to improve the tested tool to ensure that all proposed refinements were incorporated in the tool refinement process. Respondents also indicated their willingness to pay for the tested tools should they prove to be labour-saving.

Table 5-1: Agricultural Tools Selected for On-farm Trials

Cultivation Tasks To be Tested	Existing Tools to Tested	New Co-Designed Prototypes
Land Clearing	Existing traditional Hoe (with 3-5 years wear and tear)	Curved-Blade Hoe Grated Blade Hoe
Ridging	Existing traditional size Hoe (new)	Ridging Hoe with Handle to Blade Connector
Planting	Small hoes and use of hands/feet	Sasakawa Hoe Three-Blade Planter
Weeding	Existing traditional Hoe (3-5 years wear and tear)	Flat Edge Hoe Wide Blade Hoe

5.3.2 Field testing Sessions for Welded Post-Harvest Season Agricultural Tools

The following tools were selected for testing and comparison with the existing tools for the below listed labor-intensive tasks. To ensure that each group member had adequate exposure and a good understanding of what “labour-saving” criteria was being assessed during the field testing, they were trained on the testing protocols and the steps for each test to be taken. For each session, each group was asked to test the post-harvest activity using the existing methods used and compare them with the time given to complete the same task using the new prototype. 5 prototypes were tested and the research encouraged each user to provide contributions on how to improve the tools' functionality.

Table 5-2: Tools for On-Farm Time Differential Trials for Post-Harvest Activities

Post-Harvest Tasks To be Tested	Existing Tool to Tested	New Co-Designed Prototype
Pounding	Traditional pestle and mortar	Maize Grinder
Maize Shelling Groundnut Shelling	By hand or using maize cobs	Maize Sheller, Groundnut Sheller
Threshing	Threshed Using Poles & sticks	Soya and Bean Thresher
Winnowing	Traditional winnower tray	Groundnut, Soya & Bean Winnower

5.4. Results

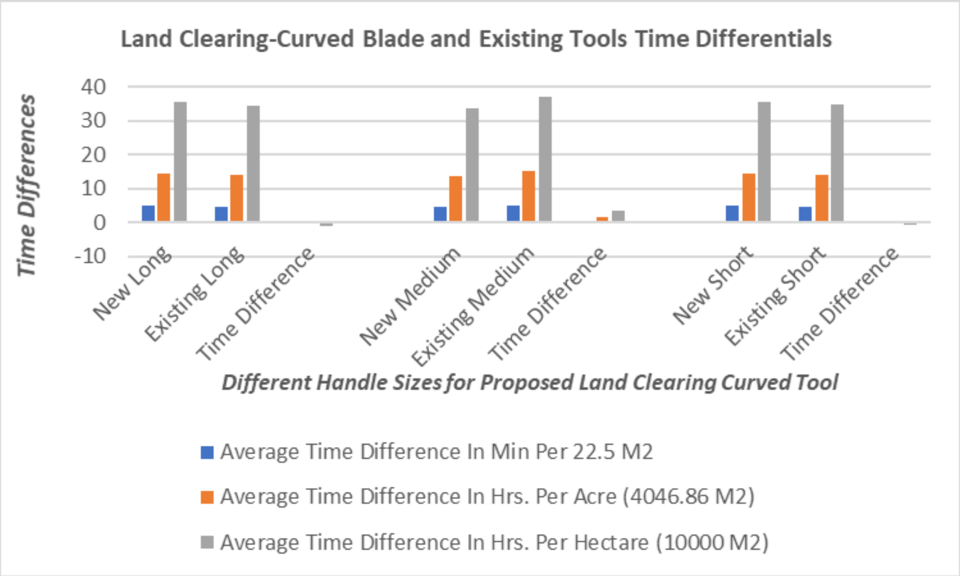
5.4.1 Time differential outputs from new and existing tools

Clearing Time Differential Trials:

Women farmers successfully tested the existing clearing tools and the new co-designed clearing prototype produced through local welding. The time taken for each tool was recorded by tool handle (long, medium and short). The curved and wide/grated blade hoes were tested comparatively with the traditional hoe that is currently used. Table 6.2.2.1 below indicates the time differential results for the land clearing tool trials.

Table 5-3: Land Clearing-Curved Blade and Existing Tools Time Differentials

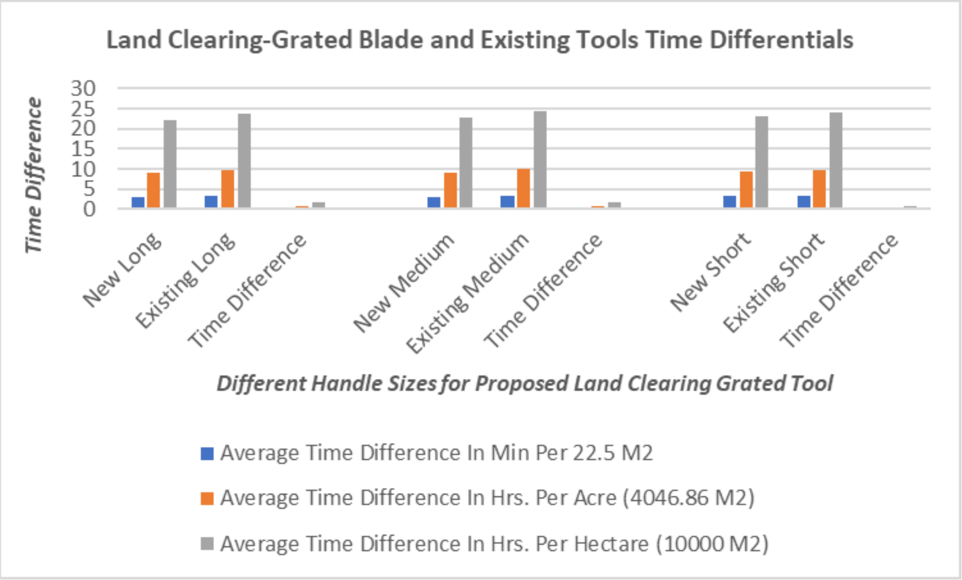
	Average Time Difference in Min Per 22.5 M^2	Average Time Difference in Hrs. Per Acre (4046.86 M^2)	Average Time Difference in Hrs. Per Hectare (10000 M^2)
New Long	4.77	14.30	35.34
Existing Long	4.62	13.84	34.19
Time Difference	**-0.16**	**-0.47**	**-1.15**
New Medium	4.53	13.57	33.54
Existing Medium	4.99	14.95	36.94
Time Difference	**0.46**	**1.37**	**3.40**
New Short	4.79	14.37	35.59
Existing Short	4.70	14.08	34.79
Time Difference	**-0.10**	**-0.29**	**-0.80**



The above results show that the new curved blade hoe performed best when produced with a medium size handle as compared to the existing traditional hoe. For both the long and short handle tests, the existing hoe demonstrated less time taken per task.

Table 5-4: Land Clearing-Grated Blade and Existing Tools Time Differentials

	Average Time Difference in Min Per 22.5 M^2	**Average Time Difference in Hrs. Per Acre (4046.86 M^2)**	**Average Time Difference in Hrs. Per Hectare (10000 M^2)**
New Long	**2.99**	**8.96**	**22.13**
Existing Long	3.21	9.62	23.77
Time Difference	**0.22**	**0.66**	**1.64**
New Medium	3.06	9.18	22.69
Existing Medium	**3.29**	**9.87**	**24.39**
Time Difference	**0.23**	**0.69**	**1.70**
New Short	3.13	9.39	23.20
Existing Short	3.23	9.68	23.92
Time Difference	**0.10**	**0.29**	**0.72**

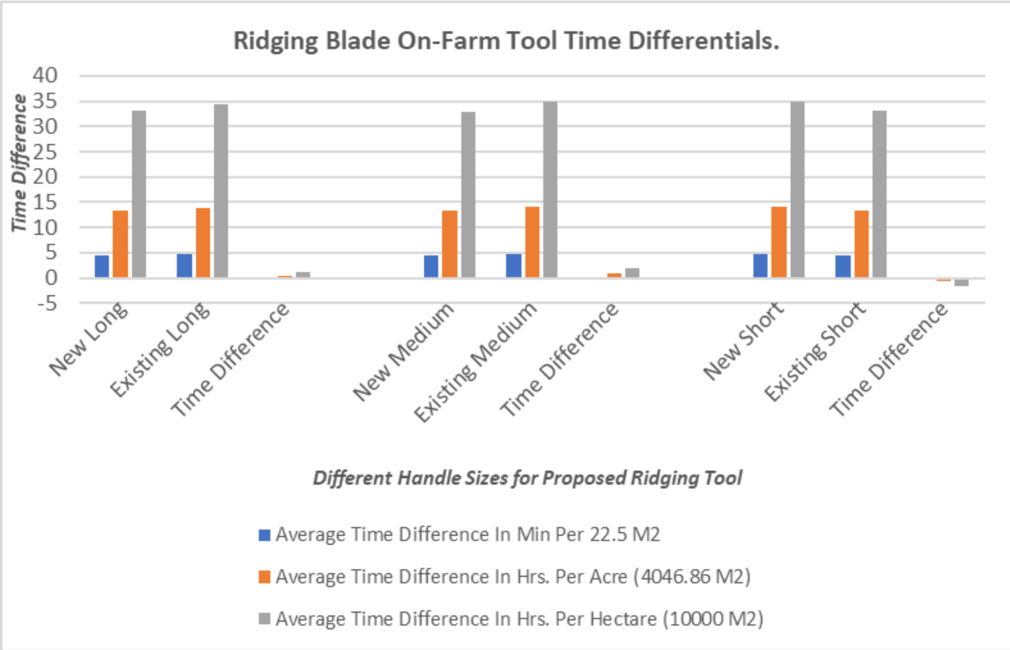


The above results show that the new grated blade hoe performed best for land clearing when produced with any of the handle sizes as compared to the existing traditional hoe. The farmers liked this tool as it was wider than the existing tool and covered more ground between the ridges that typically need frequent weeding. This tool completed the task faster and the land cleared was neater than the cleared using the existing traditional tools.

Ridging Time Differential Trials:

Table 5-5: Time differential analysis for the New and Old hoes that were used for ridging

Ridging Blade On-Farm Tool Time Differentials.			
Type of Tool Handle	**Average Time Difference in Min Per 22.5 M^2**	**Average Time Difference in Hrs. Per Acre (4046.86 M^2)**	**Average Time Difference in Hrs. Per Hectare (10000 M^2)**
New Long	4.47	13.40	33.10
Existing Long	4.64	13.91	34.38
Time Difference	**0.17**	**0.52**	**1.28**
New Medium	4.45	13.33	32.95
Existing Medium	4.72	14.14	34.95
Time Difference	**0.27**	**0.81**	**2.00**
New Short	4.70	14.09	34.83
Existing Short	4.48	13.43	33.19
Time Difference	**-0.22**	**-0.66**	**-1.64**

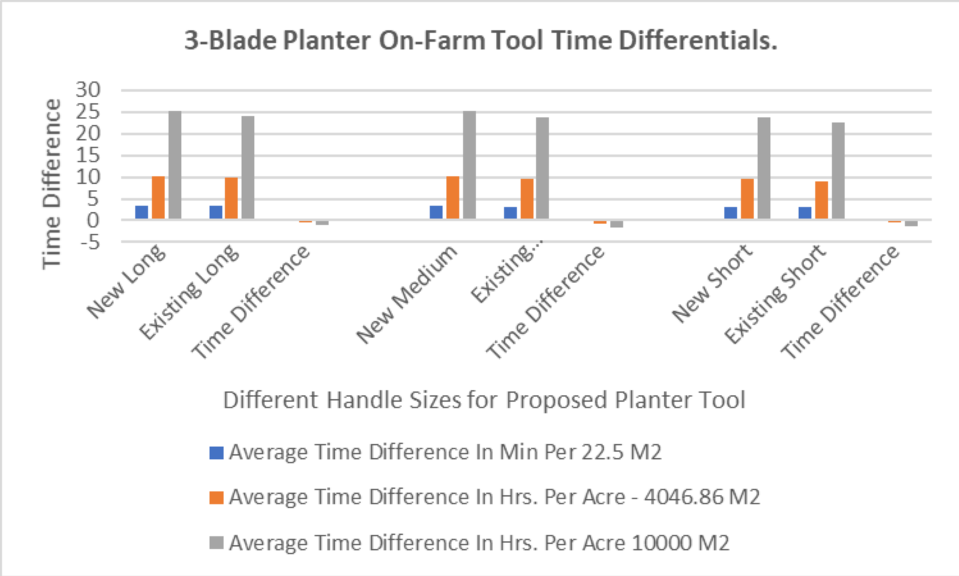


The results of the ridging trials indicate that the existing hoe is faster at the ridging activity as compared to the new tool when produced with a short handle size only. This may be because the farmers are more familiar with the existing tools as compared to the new tools or could simply be a better tool on time savings. However, the farmers preferred the new prototypes because of the hand-blade connector and the lightness of the tool when compared to the existing standard size traditional hoe found in Malawi.

Planting Time Differential Trials:

Table 5-6: Time differential analysis for the New and existing planting tools and methods

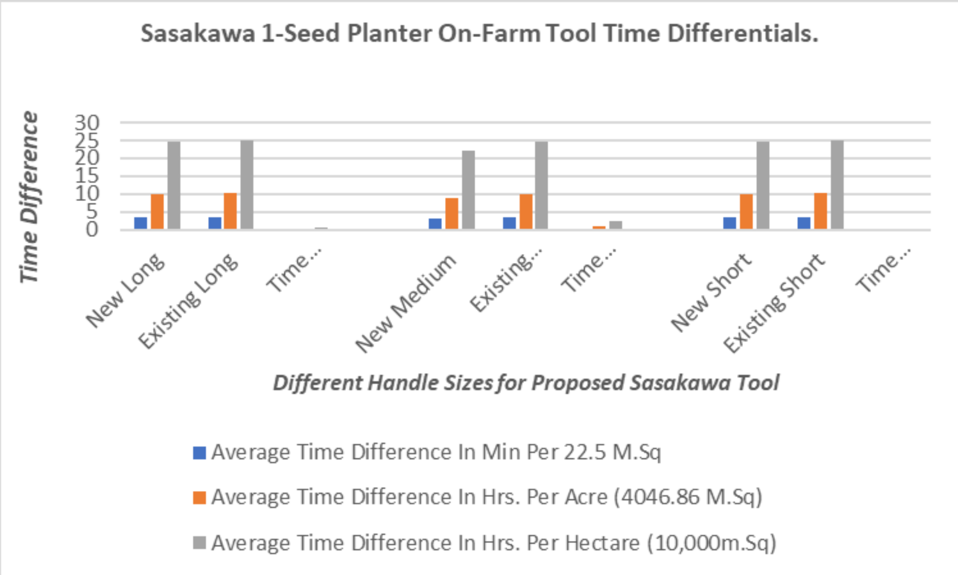
3-Blade Planter On-Farm Tool Time Differentials.			
	Average Time Difference in Min Per 22.5 M^2	**Average Time Difference in Hrs. Per Acre - 4046.86 M^2**	**Average Time Difference in Hrs. Per Acre 10000 M^2**
New Long	3.40	10.19	25.17
Existing Long	3.25	9.73	24.05
Time Difference	**-0.151**	**-0.454**	**-1.120**
New Medium	3.41	10.21	25.24
Existing Medium	3.20	9.59	23.69
Time Difference	**-0.209**	**-0.626**	**-1.550**
New Short	3.22	9.65	23.85
Existing Short	3.03	9.07	22.42
Time Difference	**-0.194**	**-0.580**	**-1.430**



The three-blade planter did not demonstrate any time savings during planting as compared to the existing methods and tools used. However, the farmers liked that it made 3 planting stations at the same time. However, to save more time than the existing tool, the farmer would need a partner to follow behind dropping the seed and covering the planting stations. Typically, this is what is done with the farmer households and therefore the farmers preference was the 3-blade planter when compared to the other tools tested.

Table 5-7: Time differential analysis for the New and existing planting tools and methods

Sasakawa 1-Seed Planter On-Farm Tool Time Differentials.			
	Average Time Difference in Min Per 22.5 M.Sq	**Average Time Difference in Hrs. Per Acre (4046.86 M.Sq)**	**Average Time Difference in Hrs. Per Hectare (10,000m.Sq)**
New Long	3.31	9.92	24.50
Existing Long	3.37	10.11	24.99
Time Difference	**0.066**	**0.198**	**0.490**
New Medium	3.01	9.01	22.27
Existing Medium	3.34	10.01	24.73
Time Difference	**0.332**	**0.994**	**2.460**
New Short	3.34	10.02	24.76
Existing Short	3.38	10.12	25.00
Time Difference	**0.032**	**0.096**	**0.240**



The results of the sasakawa planting trials indicate that all the newly produced prototypes demonstrated more time savings compared to the existing tools and methods when produced with any of the handle sizes. In addition to the quantitative analysis presented above, the research analyzed the feedback from the women innovators after testing the tools. Below is the summary of the qualitative feedback from the KIIs.

Table 5-8: Summary of Qualitative User Feedback from women smallholder farmers.

Type of Test	Name of Prototypes	Existing Tools	KII User (Tester) Feedback
Land Clearing	Curved Edge	traditional hoe (3 -5 yrs. old)	Innovator groups indicated that this new tool is fine as is and worked very well when sharpened.
	Grated	traditional hoe (3 -5 yrs. old)	Farmers asked for the grates to be removed and replaced with a wide flat blade. It was also renamed. Farmers preferred the wide flat blade as it did cleared land extremely and was more durable.
Ridging	Ridging Hoe	Best 43 Hoe	The improved hoe is perfect and ready for the market as it has the handle-to-blade connector that makes the new tool lighter than the existing traditional hoe. It is more ergonomically preferred even though the time savings were not demonstrated.
Planting	Sasakawa (1 – seed)	Small axe or hoe	The farmers would like the sasakawa blade to be slightly longer and narrower to make deeper planting stations. It would also allow the tool to be more durable. They otherwise liked the new tool.

	3-Blade Planter	traditional hoe (3 -5 yrs. old)	It is a preferred improved tool as it makes 3 planting stations at once and this saves time for the farmers for this station making activity and does not require them to bend as much as when they use the existing tools/methods. However, this tools only works well when a 2nd person follows behind to drop the seed and close the planting stations. Farmers indicated that they typically do not plant individually on their farms and could envision themselves using this tool to save time for the whole family therefore reducing their combined labour burdens during the rainy season.
Weeding	Straight Edge	traditional hoe (new–1yr old)	This new straight edge tool worked well compared to the existing tool and farmers liked how light the tool was.
	Flat blade	traditional hoe (new–1yr old)	Remove the grates with flat blade to clear land better, increase the tool's life span and make the tool more durable.

Figure 5-1: Welded cultivation prototypes co-designed with women farmers.

Figure 5-2: Women farmers testing land clearing tools to compare time taken.

5.4.2 Metal Cast Prototypes for Phase II On-Farm Testing

The analysis of the seven welded prototype tools indicated that the new hand-held welded co-designed prototypes demonstrated time savings capabilities as compared to the existing tools. However, the data generated in earlier stages of field testing with welded versions of the tools was not statistically conclusive regarding and required further field testing with more durable metal cast prototypes to generate more conclusive data to identify which prototypes demonstrate the most significant labour savings. In addition, qualitative feedback from the women farmers from the earlier field testing suggested that the tools may have improved ergonomic attributes and may also be less energy demanding. However, such qualitative feedback required further investigation to determine whether there was any evidence to support such claims. For the metal cast tool-prototyping phase of the research, the seven prototypes of the hand-held tools were produced from hardened steel metal casts.

Table 5-9: Metal Cast Prototypes Tested by Women Smallholder Farmers in Malawi

Cultivation Task	Metal Cast Tool Prototypes	Existing Tools Used by Women Farmers	No of metal casted prototypes made
Land Clearing	1) Curved Edge	traditional hoe (3-5 yrs. old)	3
	2) Grated	traditional hoe (3-5 yrs. old)	3
Ridging	1) Ridging Hoe	Best 43 Hoe – traditional hoe	3
Planting	1) Sasakawa Hoe	Sticks/Hands/Legs, Small Axe	3
	2) 3-Blade Planter	traditional hoe (3 -5 yrs. old)	3
Weeding	1) Straight Edge	traditional hoe (New–1yr old)	3
	2) Flat blade	traditional hoe (New–1yr old)	3

Figure 5-3: 3 Blade Planter Mould and Metal Cast Prototypes

Figure 31a: Weeding and Clearing Metal Cast Prototype and Weeding Flat Blade Cast Mould

Figure 31b: Sasakawa Planting Hoe Mould and Metal Cast Prototypes

The on-farm trials for the metal cast were conducted using the same testing protocols that were used to test the welded prototypes in phase I. Based on the results of the on-farm testing using metal cast prototypes, the research was able to compile time differential analysis and key user feedback from women smallholder farmers regarding the tools' weight, length and general tool dimensions. In addition, farmers who tested the tools were asked to provide feedback the new prototype's quality of work done, time taken, energy used, refinements to be made and overall preference. The women farmers' ergonomic preferences for the tools tested were also captured as well as their willingness to pay for the new prototypes and related prices they would be willing to pay. The on-farm trials of the metal-cast prototype tools were successfully conducted with the support of the participating women farmers groups and LUANAR Agri-Engineering department.

Hoe Type	Clearing - Curved (time hours)	Clearing – Wide/Grated (time hours)	Ridging (time hours)	Sasakawa (time hours)	3-Blade Planter (time hours)
New - Long	0:04:48.43	**0:02:59.30**	**0:04:28.07**	**0:03:18.47**	**0:03:23.79**
Old - Long	**0:04:36.89**	0:03:12.43	0:04:38.50	0:03:26.47	0:03:14.86
New - Medium	**0:04:36.28**	**0:03:03.80**	**0:04:26.86**	**0:03:00.46**	0:03:24.47
Old - Medium	0:05:19.00	0:03:17.50	0:04:43.00	0:03:24.85	**0:03:12.00**
New - Short	0:04:47.54	**0:03:07.97**	0:04:41.78	**0:03:20.57**	0:03:13.21
Old - Short	**0:04:41.82**	0:03:13.67	**0:04:28.78**	0:03:22.50	**0:03:01.57**
P.value	**0.951**	**0.966**	**0.919**	**0.903**	**0.75**

Table 5-10: Time Differential & User Feedback on Existing & Co-Designed Metal Cast Tools

Type of Trials	New Prototypes	Existing Tools	Time Differential Analysis	User (Tester) Feedback
Land Clearing	Curved Edge, & Wide Blade	Std size hoe (3 -5 yrs. old)	The clearing curved hoe's time use was better than the existing tool when using the medium handle only. The clearing wide blade (formerly grated) hoe's time user was better than the existing hoe for all the tested tool handles.	Women farmers asked to have the grates and "windows" removed from the blade to have a flat blade and full blade to increase the tool's life span and durability and clear the land better.
Ridging	Ridging Hoe	Best 43 Hoe (std size hoe)	The co-designed ridging hoe took less time to ridge the same piece of land that the existing tool when using when using the long and medium handles.	Women farmers indicated that this prototype is market-ready and should be disseminated to others
3-blade planter	3-blade planter	Planting with hands and feet & Planting	As noted during the welding tests, the metal cast prototype also performed well only on saving time to make planting stations. It can make 3 planting stations at once compared to the	Farmers indicated that they typically do not plant individually on their farms and could envision themselves using this tool to save time for the whole family therefore reducing their combined labour burdens during the

		using sticks	existing hoe. However, this tools only works well when a 2nd person follows behind to drop the seed and close the planting stations.	rainy season. They preferred this tool to the existing tool also because it does not require them to bend as much as when they use the existing tools/methods.
1-seed Planting	Sasakawa Hoe,	Small axe or small hoe	The new co-designed Sasakawa hoe performed better on time taken per activity as compared to existing tools when using any of the handle lengths.	The farmers want the blade to be slightly longer and narrower to make deeper planting stations. The tool is market-ready.

5.4.3 Post-Harvest Season Prototypes Tested

Maize Shelling Prototype Compared to Maize Shelling by Hand

Women farmers compared times taken to shell 1kg of maize by hand to the time taken to shell the maize using the women farmer co-designed maize sheller that is hand-powered. The results of the maize shelling trials conducted with women farmers are presented in the table below.

Table 5-11: Time taken while using existing and new technology in shelling maize

Type of Maize Sheller	Average Time (hh:mm:ss.ss) Taken to shell 1kg of maize
Existing shelling technique	0:03:40.63
New (innovation)	0:01:29.47
Overall mean	**0:02:35.05**
Sig.	**<0.001**

Figure 5-4: Hand-shelling maize versus the women farmer co-designed maize sheller

Based on the table above, the results show that the women farmer co-designed hand-powered maize sheller generated time savings for women smallholder farmers of 18 hours per ton of maize (n = 37 independent tests), compared to the women smallholders existing maize shelling technique (mainly using empty maize cobs as scrappers or hands). The results presented above are statistically significant as evidenced by the P.value <0.001.

Maize Grinder Prototype Compared to Maize Grinding Using a Pestle and Mortar

The research recorded the time taken for women farmers to grind 1kg of maize using a traditional pestle and mortar and compared it to the time taken to shell the maize using the women farmer co-designed maize grinder that is hand-powered. The results of the maize grinding trials conducted with women farmers are presented in the table below.

Table 5-12: Time taken while using existing and new technology in grinding maize

Type of technology	**Average Time for a Grinder (hh:mm:ss.ss)**
Old	0:05:59.39
New (innovation)	0:02:37.81
Overall mean	**0:04:18.60**
Sig.	**<0.001**

Figure 5-5: Maize grinding: traditional methods versus new prototype.

Based on the maize grinding trials conducted by this research, the women farmers co-designed maize grinder generated labour savings for women smallholder farmers of 58 hours per ton of maize (n = 35 independent tests), compared to the women smallholders existing maize shelling technique of using the traditional mortar and pestle. The results presented above are statistically significant as evidenced by the P.value <0.001.

Groundnut Sheller and Winnower Prototype Compared to Using Hands

The research recorded the time taken for women farmers to shell 1kg of groundnuts by hand and compared it to the time taken to shell the maize using the new co-designed groundnut sheller and winnower that is hand-powered. In addition, the time taken to winnow the shelled groundnuts by hand or using the prototype was also recorded and added to the time taken to shell the groundnuts.

Table 5-13: Time taken to shell and winnow Groundnuts

Type of technology	Groundnut Sheller & Winnower (new) Average Time (hh:mm:ss.ss)
Old	0:35:59.89
New (innovation)	0:02:16.51
Overall mean	**0:19:08.20**
Sig. (0.05)	**<0.001**

Figure 5-6: Shelling groundnuts versus new prototype.

The results (n = 27 independent tests) indicate that use of the women co-designed groundnut sheller and winnower can generate labour savings for women smallholder farmers of **571 hours per ton (1000 kg)** of groundnuts, compared to the women smallholders existing groundnut shelling technique which is by hand. The results presented above are statistically significant as evidenced by the P.value <0.001.

Soya Thresher Prototype Compared to Using Sticks and Poles

The results of the 1-day tool testing sessions with smallholder farmers were inconclusive. Therefore, further tests were required. However, due to resource limitations, this was not possible during this research.


Figure 5-7: Soya thresher and Winnower Co-Designed Prototype

Prototypes (metal cast) for Phase 2 Testing of Post-Harvest Technologies

The results from the phase 1 on-farm testing demonstrated high time-saving capabilities for the post-harvest innovations field testing by women innovator groups. The welding option was considered reliable and is more cost-effective than metal casting. Therefore, metal casting was not explored for the post-harvest agri-processing technologies.

5.5. Discussions and Conclusions

Based on the results presented for the welded and metal cast hand-held cultivation tools, the newly produced improved tools demonstrated on average less time taken per activity. However, as presented, these results were mostly not statistically significant. The metal cast prototypes demonstrated slightly higher time savings that the prototype tools. This could be as a result of the different materials used to produce the prototypes. In addition, women smallholder farmer innovator groups provided their feedback on their preferences for the tools tested which indicates a preference for the co-designed cultivation season prototypes as they claimed that the new prototypes saved them noticeable time and because the tools were lighter and more durably made.

With the old hoe handles, a specific natural shape of a tree branch is required to use for the handle of the hoes. The process of looking for such a branch can be exhausting, and a lot of work is later needed to work on the tree to make it a hoe handle. All that requires specific skills and a lot of time which is not the case with the new hoe handles design. All the new co-designed prototypes have handle-to-blade connectors and are in line with the preferences of the users. Local timber vendors were identified and engaged for the production of tool handles in Lilongwe, Malawi. In the Nkhamenya region, the longer handles were preferred while in the Central region closer to Lilongwe, longer handles are culturally viewed as the “lazy tool” and therefore, most of the women preferred the shorter handles. Farmers tested all tool handles and based on the outcomes of the tool trials for both welded and metal cast tools, made their observations that were used to make the final decisions on the tools that demonstrated the highest time savings and the associated handles they used.

While the results of the cultivation tools results do not seem very significant, the reactions from the women farmers throughout the testing processes were very positive with regards to the tool trials and the new prototypes. The smallholder farmers fully participated in the testing sessions, followed all protocols and provided concise and clear feedback that was instrumental for this research. The farmers stated that the process of designing the tools and testing them with the existing tools and methods transformed them into creative thinkers. The full details of the empowerment and other effects of this research on the women farmers and their households is presented in the last chapter.

As demonstrated by the outcomes of the participatory tool trials. robust results were generated for the post-harvest tools, which indicate that these prototypes are now ready for mass production and dissemination to similar target groups. The overall time savings demonstrated by all the newly produced post-harvest prototypes were very significant and demonstrated the ability of women smallholder farmers to co-design labour saving tools that are customized to their cropping systems.

The results also show that these tools can be produced frugally for participatory on-farm testing with minimal costs and how local prototyping can be used to rapidly produce tools using farmers' inputs that don't need to take years for R&D as it took a short time to get the tools back for testing. Therefore, it is pertinent for tool producers to consult with and incorporate the inputs of women smallholder farmers when producing agricultural tools and other products. It is also crucial to assess the available local resources and use them efficiently to minimize production costs and set affordable prices for labour-saving tools that are in high demand by smallholder farmers in rural Malawi.

Furthermore, this research demonstrated the need for robust field-testing protocols and data collection methods to develop an evidence base of the tested innovations. The results also further support that through 3D printing, welding and metal casting rapid prototyping options, local producers have the potential and can produce agricultural tools that are user-tailored to be returned to women smallholder farmers for testing and refinement.

The overall findings prove that women smallholder farmers need to be included in the tool testing and refinement processes to ensure that their needs and contributions are taken into consideration in a participatory technology development process for each tool that is introduced into their local markets. Improved agri-tools and implements have demonstrated the potential to decrease labour intensive work and can have major impacts on the target groups. The following chapter 6 highlights the approach taken to conduct energy exertion on-farm field trials to further build the evidence base of labor-saving tools.

6. CHAPTER 6: APPLICATION OF WEARABLE KINEMATIC SENSORS

Most of the labour force in the Malawian agriculture sector are smallholder farmers who mostly farm for subsistence purposes and lack access to any technology. As a result, their tools are basic in nature and as a result, a lot of time and energy is spent completing their required tasks. The component of the overall research captured in this section aimed to incorporate innovative methods to test the energy exertion levels of smallholder farmers when using their existing tools as compared to improved customized tools that are tailored to each agricultural activity. To encourage innovation, the research opted to explore the use of kinematic sensors to capture data from the on-farm trials that would be used to measure the farmers' energy exertion when using different tools.

6.1. Analysis of Energy Exertion Assessment Technologies

Labour saving technologies aim to reduce time and energy. The measurement of time and energy usage associated can be challenging, particularly for measurement of energy use. In addition, ergonomics can also have a bearing on user preferences for different tools and technologies. While surveys of users can elicit valuable data regarding their perceptions of time, ergonomic and energy gains arising from use of any new technology and tool, such perception-based surveys can be subject to bias and inaccuracies, and typically do not measure time, energy or ergonomics directly. This research aimed to incorporate quantitative assessment methods as well to reduce the inaccuracies of qualitative research.

Technical feasibility assessments have been conducted that analyze requirements and applicability of wearable sensors to human energy expenditure, e.g. to investigate how sensors can be used in monitoring of gain and fall in older people (Wang et al., 2006, Fukatsu and Nanseki, 2009, Cvetković et al., 2013, Rucco et al., 2018, Godfrey, 2017). For instance, some authors have compared and evaluated three different sensor configuration sets: (i) *a heart rate monitor and two inertial sensors attached to the users thigh and chest* (Mukhopadhyay, 2015, Fiorini et al., 2018); (ii) *a heart rate monitor with an embedded inertial sensor and a smart phone carried in the pocket* (Cvetković et al., 2013, Mukhopadhyay, 2015, Fiorini et al., 2018); and (*iii) only a smart phone carried in the pocket* (Saidan and Al-Dossari, Pei et al., 2013, Cvetković et al., 2013). The accuracy of the models was validated against indirect calorimetry using the Cosmed system and compared to a commercial device for energy expenditure Sense Wear armband. The results indicated that models trained using relevant features can perform comparable or even better than available commercial device (Cvetković et al., 2013, Luštrek et al., 2012) (Cvetkovi ́c, Bo ̌zidara et al, Towards Human Energy Expenditure Estimation Using Smart Phone Inertial Sensors).

There are several methods to estimate the human energy expenditure. Direct calorimetry measures the heat output of a person (Hibi et al., 2013) i.e. the heat produced by human body while exercising. This is the most accurate method, but it can be used only in a controlled environment (e.g. laboratory) (Levine, 2007). It measures the energy expenditure over medium periods of time (hours). Indirect calorimetry measures the amount of inhaled and exhaled oxygen and CO_2 during rest and steady-state exercise, which is linked to the expended energy. It is fairly reliable and can be used in field conditions, even over short periods of time (minutes). However, it cannot be used in everyday life, since it requires a breathing mask (Levine, 2007).

Measuring physical activity using doubly labeled water (i.e. water labeled with deuterium and oxygen-18), provides a gold standard, where it is possible to measure the amount of exhaled carbon dioxide by tracking its amount in water. This method can be used in everyday life, but it measures the energy expended over longer periods of time and is expensive. It is also fairly reliable and can in principle be used in everyday life, but only over long periods of time (days or weeks).

As the above options were not feasible for this resource-limited research, the most affordable approaches were determined to be commercial wearable sensors embedded in armbands and other devices, which are moderately accurate and reliable. These can be used in everyday life over short periods of time and given the increasing ubiquity of such sensors, they seem to be the most promising tool for energy expenditure estimation Luštrek et al., 2012 Mitja et al). A Fitbit and skin-temperature sensor were also considered, but preliminary assessments showed no benefit compared to the costs foreseen. In this paper, a method for activity recognition and energy expenditure estimation using a wearable sensor is explored.

Inertial sensors as motion sensors are already very popular in different domains such as gaming industry, healthcare and medicine and security (Cvetković et al., 2013, Fiorini et al., 2018, Niestroj). Their accessibility, ease of use, and understandable concept of accelerometry help broadening its applicability domains on a daily basis. For instance, even running shoes can contain an accelerometer, while an average smart phone contains a wide range of sensors, including an accelerometer (Cvetković et al., 2013, Luštrek et al., 2012).

Most methods for energy expenditure estimation using wearable sensors seek linear or nonlinear relations between the energy expenditure and the accelerometer outputs. The most basic methods use one accelerometer and one linear regression model (Crouter et al., 2012). The estimation accuracy can be improved by multiple regression models and complex attributes. The regression method by (Crouter et al., 2012) is currently among the most accurate. It uses one accelerometer attached to the hip. In the first step it classifies a person's activity into sitting, ambulatory activity or lifestyle activity. In the second step, it uses a linear regression model for the ambulatory activity and an exponential regression model for the lifestyle activity. The weakness of this method is the exclusion of some activities such as cycling, and a larger error for the upper body due to the sensor placement. Some methods use a human kinematic model, from which the kinetic energy required for the movement can be computed. The movement is estimated using accelerometers attached to the body. However, this requires the integration of acceleration data, which can amplify sensing errors and the use of many accelerometers ((Luštrek et al., 2012).

The research investigated various options for energy analysis and opted for the Shimmer Kinematic Sensor Equipment that is currently being applied to measure acceleration and other performance factors in athletes in Ireland and other countries across Europe (Loose and Orlowski, 2013, Torres, 2013). These are wearable wireless sensors with an integrated motion processor, accelerometer, gyroscope, magnetometer, and altimeter, all which simultaneously record required data. This chapter provides an overview of the approach used to test and apply the Shimmer testing kits to conduct on-farm acceleration and angular velocity tests during field trials of the newly designed cultivation tools and existing cultivation tools used by the women farmers in Malawi. A formula for the calculation of approximate energy exerted when using agricultural tools is derived and applied to analyze the recorded data. The Shimmer kinematic sensors are originally developed for sports and fitness applications and for this research, were used as experimental instruments during for on farm trials and applied to determine the energy exertion for each of the on-farm tool trials of existing tools compared to the newly produced tools that were co-designed with the women smallholder farmers.

6.2. Research Objectives

The research goal for this chapter was:

- *to investigate the energy consumption of the existing tools in Malawi in comparison to the new women farmer co-designed prototypes that were introduced in chapter 4 of this thesis.*
- *To test kinematic sensors for on farm tool trials and recommend adaptations for these sensors to be more suited to agricultural settings.*

6.3. Research Methodology and Equipment

The research collected data on existing agricultural tools including mass and height as well as user profiles, to be incorporated into the energy exertion analysis. Before conducting field trials, pre-trials were made to test the best data collection intervals to calibrate the shimmer sensors. The shorter the data capture intervals, the more data the shimmer sensors capture. Therefore, the research team set the sensors to the shortest time intervals to increase the accuracy of the data points that would be tallied to achieve the total energy consumed in Joules (J). The researcher engaged the shimmer support team to ensure the equipment was working well and could measure the acceleration and angular velocity for each trial.

6.3.1 Shimmer Data Management

Shimmer is an Irish company that develops and sells a wearable sensor platform and equipment that allows for simple and effective biophysical and kinematic data capture in real-time for a wide range of application areas (www.shimmersensing.com). The initial approach adopted in the development of the shimmer wireless sensor platform was to increase the application of sensor technology in healthcare by focusing on commercially viable features valuable to both systems engineering researchers, biomedical researchers, and clinicians (Loose and Orlowski, 2013, O'Donovan et al., 2009). The shimmer wireless sensor platform has users in over 30 countries , including leading universities and corporate research and development organizations. It forms a key component of the BioMOBIUS research platform, which represents a collection of tightly integrated hardware, and software components enabling rapid prototyping of biomedical research applications (Kugler et al., 2012, Burns et al., 2010b). In this study, the shimmer wireless sensor platform was used to capture raw data that was analyzed to measure energy exertion associated with the use of different farmer co-designed tools relative to existing tools. The Shimmer3 Sensor Unit is a small device, housing multiple sensors that are docked in its station. The device is activated either upon removal from the base station or by pressing the orange button on the front of the unit, depending on settings available while connected to the base station and PC via Consensys. Once the unit records data values, the data can then be downloaded to a PC for investigation via connection to the base station and Consensys or via Bluetooth.

Table 6-1: Specifications for the Shimmer sensors

SHIMMER SENSOR SPECIFICATIONS		
Sensor Features	**Calibrated Units**	**Description**
Timestamp	Milliseconds	Time of data point
Acceleration Wide Range (WR): X, Y, Z	Meters/seconds2	Handles large fluctuations
Acceleration Low Noise (LN): X, Y, Z	Meters/seconds2	Handles smaller precision values
Gyrometer: X, Y, Z	Degrees/second	Returns angular velocity values
Magnetometer: X, Y, Z	Local flux	Returns strength and direction of local magnetic field
Pressure	Kilopascals	Scalar ambient atmospheric pressure
Temperature	Degrees Celsius	Scalar ambient temperature
Battery Life	Millivolts	Scalar battery voltage

Data collected via the Shimmer Base Station was initially downloaded as a .csv (Comma Separated Values) file from the sensors after each trial. The Accelerometer WR, Accelerometer LN, and Magnetometer sensors provided the highest accuracy for classification as observed by other research (Blank et al., 2016). As the shimmer technology is experimental in the agricultural research arena, there is no existing methodology on how to apply this technology to accurately measure energy exertion levels for on-farm tool trials. The shimmers were calibrated to collect data on the X, Y and Z-axis acceleration points based on capture intervals set at 51.2Hz. i.e. to 51.2 cycles per second. Data captured for each user that tested the existing and new tools included:

1. ***Tool Acceleration:*** when user is at "work" using new co-designed tools versus the existing tools.
2. ***Tool Angular Velocity*:** Captured in degrees/second when user is at "work".
3. ***Number of Turns*:** Each user completed 20 turns using each tool tested (new and existing tools using long, medium and short handles).

6.3.2 Testing Protocols

The research aimed to have robust user data as this will be used for the energy exertion analysis where user weight is crucial. The weight of tools was also necessary to get existing tools that were in comparison by weight and height for accurate time comparison by activity and user. Each user tested the new farmer-designed prototypes twice and the existing ones twice with alternating handles that were ranked as "Long", "Medium" and "Short". As indicated in the previous chapter, this research determined through focus group discussions that smallholder farmers in the Central region prefer shorter handles while those in the Northern part of Malawi prefer longer handles. The data collected in the initial phase as captured in chapter 4 on handle preferences was used to determine the average length for the "long, "medium" and "short" handles that were assembled and used for the on-farm tool trials to determine the most suitable handle length for the end-user. Each user therefore tested 2 heights for the new tools and 2 heights for the existing tools during each trial run. Each tool was tested was tested by an average n=48 users.

To accurately capture the shimmer data, the research observed below additional protocols:

Land size: The number of turns for each selected user was counted when the tester completed 30 meters of trial plots. This was completed for each farmer testing both the existing tools and new farmer co-designed tools.

On station Calibration tests: The shimmer trials for the new and existing agricultural tools were conducted nearby the CIAT office at the Chitedze Research station where the research was hosted. As there were power outlets, this enabled the use of the sensor docking unit. Shimmer sensors were charged and placed on the existing tools and new farmer co-designed prototypes by activity tested. Each of the tests were conducted in order of activities carried out in the farming season. 12 women were selected to test each tool and the field observers counted 20 turns for each tool tested. Data was captured on the shimmer sensors for each tool that was later used to calculate the energy exerted by each user for the same number of turns.

Once all farmers completed the trials, their user profiles and data from the sensors were used to produce energy output data to determine the average energy exertion for a typical woman smallholder farmer for each tool tested. These results were compiled together with the time differential results from chapter 5 to create the evidence base of the tools that demonstrated the most time and energy savings.

6.3.3 Formulas and Calculations

The research was supported by, Mr. Ashenafi Tariku, an Ethiopian-Canadian volunteer engineering consultant who developed all the formula described below that was required to make the energy use calculations for all tested prototypes based on the data from the shimmer sensors. The data sets captured using the shimmer sensors during the on-farm trials were then used by the PhD researcher to perform calculations in excel using the derived formula and the results of the derived energy exertion estimates are presented below. More details on the formula development are available as supplementary data.

The aim of using the shimmer sensors was to determine the energy spent as the woman smallholder farmer moved the tool from the highest point of the turn to the ground and back up to the highest (starting) point. As it may be difficult to accurately calculate the air friction, and as the effect of the air friction was approximately the same during the trials of the existing and the new co-designed prototypes, the research assumed that the energy spent in moving the hoe through the turn will be equal to the work done therefore:

Formula 1: Energy spent = Work done,

Where;

- *W is the work in Joules (J or Kgm2/s2)*
- *F is the force applied to the tool in Newtons (N or Kgm/s2)*
- *D is the distance that the tool moves in the direction of the force in meters(m)*

For the field trials, the raw data from the shimmer kinematic sensors logged instantaneous acceleration rates in the X, Y and Z axis at the sampling rate of 51.2 cycles per second. From this data, the research calculated the total acceleration instantaneous using the formula given in the Shimmer manual i.e. the total acceleration for each user is the square root of the square of all 3-dimensional acceleration data sets captured as below:

Formula 2: |A total|=Sq. Root of (Ax2+ Ay2+Az2)

From this instantaneous acceleration, the instantaneous force being applied to the tool is calculated using the formula:

Formula 3: Force = Mass of the tool x |A total|

Using the mass of the tool, the research could then figure out the instantaneous force being applied on the tool at that particular moment in time using the formula:

Formula 4: Work(I) (T1- T2)= Force Total (I) x D1 = Mass of the tool x |A total(I)| x D1

Where;

- *Work(I) is the work done for 1 interval of data collected from the shimmer Sensor*
- *Force Total (I) is the instantaneous force calculated for 1 interval of data collected from the sensor*
- *|A total(I)| is the instantaneous acceleration calculated from the X, Y and Z shimmer data collected*
- *D1 is the distance (angular) travelled by the tool for 1 interval of data collected from the shimmer sensors.*

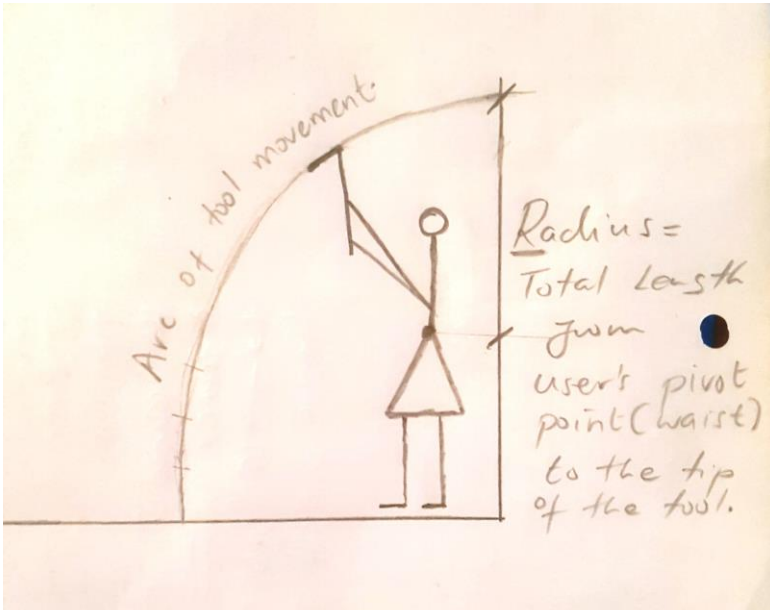


Figure 6-1: Tool Movement Radius: User's pivot point to the tip of the blade.

The only unknown entity in the formula above is D1, which in turn is calculated using the formula:

Formula 5: D1= α x r

Where;

- *D1 is the distance (angular) travelled by the tool for 1 interval of data collected from the shimmer sensors.*
- *α is the radian displacement between Time 1 and Time 2*
- *r is the total combined length of the tool handle and the length the arm of the farmer.*

To find α, use the angular displacement formula:

Formula 6: α = wt

Where;

- *α, is the angular displacement in radians*
- *w is the angular velocity in radians per second*
- *t is the time taken for one interval of data collected from the shimmer sensors, (1/51.2) seconds.*

As the angular velocity is captured by the sensors in degrees per second, the conversion rate used is:

1 degree/second = 0.017453293 rad/sec

or

1 rad/second = 57.29578 degrees/second

As gravitational considerations have not yet been accounted for, the effects need to be taken into consideration when deriving the formula. When the user operates a tool, the downward force is a positive as less energy is used. However, the upward force of lifting the tool back up to the starting point is a negative one as more effort will be required to lift the tool. Hence, the positive and negative forces cancel each other out and will therefore have no effect on the overall exertion levels of the user.

6.3.4 Tools Selected for On-farm Energy Exertion trials

The rainy season (hand held agricultural tool prototypes) tool testing consisted of land clearing, ridging and planting trials conducted with the women smallholder farmers where the number of turns taken per tool (existing versus new farmer-designed) was recorded for the same agricultural task (e.g. ridging or clearing a defined plot size of (30m x 0.75m). The tools tested were:

Table 6-2: Tools selected for on-farm energy exertion trials.

Type of Test	Number of Prototypes	Existing Tools
Land Clearing	1- Curved Edge, 2- Grated	traditional hoe (3 -5 yrs. old)
Ridging	1- Ridging Hoe	Best 43 Hoe
Sasakawa (1-seed) Planting 3 – Seed Planting	1 - Sasakawa Hoe, 2 - 3-Blade Planter	Sticks/Hands/legs, small axe traditional hoe (3 -5 yrs. old)
Weeding	1 - Straight Edge, 2 - Flat blade	traditional hoe (new–1yr old)

6.3.5 Assumptions made

- Calculations were made as if the person was standing in one position as was done during calibration use which reduces the precision since in reality, the farmers move from end of farm to the other.

- Although there is a slight movement made, there is an assumption that the hand at the end of the handle is a stationary axis of rotation.

- The research took the average of the initial and final acceleration and angular velocity of each interval (the time between 2 lines in the spreadsheet) and assumed that to be constant for the interval throughout all data capture intervals.

6.3.6 Key Informant Interviews with Each Tool Tester

This was conducted at the end of each test to collect qualitative and quantitative feedback on each tool trial to be incorporated for further review and comparison with the time differential and energy analysis. KIIs were conducted at the beginning and end of each field-test to collect feedback to be incorporated with the energy exertion results. For each trial session, each user completed a questionnaire to provide feedback on their perception of the tool before testing it as well as after completing the tool trial. Participants were asked to provide their preferred tool dimensions including handle length and weight, blade length, width and weight as well as the handle to blade angles. Farmers also ranked the tested tools for ease of use, energy exerted and overall ergonomic suitability of the tool. In addition, they were asked to share their ideas how to improve the tested tool to ensure that all proposed refinements were incorporated in the tool refinement process. Respondents also indicated their willingness to pay for the tested tools should they prove to be labour-saving.

6.3.7 Data Analysis

The data from the shimmer sensors was imported and analyzed using MS Excel. Each user had four sets of data. Data collected after energy assessment trials were subjected to mean comparisons in SPSS, to establish if there were statistical differences in energy use between existing and new tools of different handle lengths (short, medium and long) through analysis of variance. Results were summarized to tables with the aid of Microsoft excel and are presented below.

6.4. Results

6.4.1 Energy Exertion Analysis of Land Clearing Tools

The women smallholder farmers completed field calibration tests for the newly co-designed curved blade prototype and the existing tool typically used which is a traditional hoe with roughly 3-5 years of wear and tear as per the innovator groups engaged throughout the research. The average results of energy exertion per tool are presented in table 75 below.

Table 6-3: Energy Exertion Comparison - Curved Blade Clearing Hoe and Existing Hoe

Curved blade land clearing hoe versus traditional hoe	**Average energy (MJ)** 20 turns for each tool tested
New Long - LN	4758856.25
Existing Long - LN	3534167.88
New Long - WR	4582061.06
Existing Long - WR	3103629.59
New Medium – LN	**3980370.09**
Existing Medium - LN	5850648.90
New Medium - WR	**3805640.20**
Existing Medium - WR	5956925.61
New Short - LN	7511217.83
Existing Short - LN	4152009.35
New Short - WR	7176786.66
Existing Short - WR	3686110.14
Sig.	**0.56**

The table above shows the mean comparison of energy that was used when using existing tools compared to the new co-designed curved blade clearing tools with different handle lengths (short, medium and long). The results indicate that there are no significant differences in energy used in all the hoes as shown by the P.value>0.05 (0.56). However, the new tool demonstrated some energy savings when assembled with the medium length hoe that is one meter long. Considering the challenges noted below during the trials, it is possible that with these factors kept constant, the new tools may have demonstrated even higher energy savings. This finding also demonstrates that based on the assembly of the tool, and ergonomic suitability, the user's energy exertion levels may increase or decrease as was seen during the trials with the handle preferences.

This curved land clearing tool has a smaller blade and is in general a much lighter tool than the existing hoe sold in Malawi. The results of the energy assessment indicate that this new tool showed less energy exertion during the trials than the existing tools for the long and short handles and a minimal but still positive energy exertion difference for the medium handle new tool compared to the existing tool.

Wide Blade Hoe Compared to existing traditional hoe

For the second land clearing trials, the women farmers tested the second co-designed prototype against the existing two to three-year-old traditional hoe available in Malawi. Farmers were asked the test both tools and make twenty turns for each tool they tested. Table 76 below presents the energy use analysis results.

Table 6-4: Energy Exertion Wide Blade Clearing Hoe and Existing Hoe

Handles for Wide Blade land clearing Tested	Average energy (KJ) 20 turns for each tool tested
New Long - LN	**2255186.62**
Existing Long - LN	4032732.10
New Long - WR	**2094440.92**
Existing Long - WR	3545672.31
New Medium - LN	3463090.96
Existing Medium - LN	3132450.84
New Medium - WR	3181749.17
Existing Medium - WR	2873921.78
New Short - LN	2382554.14
Existing Short - LN	2248469.49
New Short - WR	2205312.08
Existing Short - WR	2001516.89
Sig.	**0.67**

Results summarized in the table above shows mean comparison of energy that was used when using old and new grated land clearing hoes, which had different handle lengths (short, medium and long) and types (LN and WR). The results showed that there were no significant differences in energy used in all the hoes as indicated by the P.value>0.05 (0.67). However, the new tool demonstrated some energy savings when assembled with the long length hoe that is 1.5 meters long. Considering the challenges noted below during the trials, it is possible that with these factors kept constant, the new tools may have demonstrated even higher energy savings. This also demonstrates that based on the assembly of the tool and ergonomic suitability, the user's energy exertion levels may increase or decrease as was seen during the trials.

The new prototype has a shorter and wider blade than the existing traditional size hoe as the women smallholder farmers wanted this tool to cover all the spaces between the ridges when they clear the land. The clearing wide blade (formerly grated) hoe showed much less energy exertion during trials than the existing tool for the long handle, medium handle and short handles tools. User feedback after the tool trials shows that women farmers would like to have the grates and "windows" removed from the blade to have a flat and full blade to increase the tool's life span and durability.

6.4.2 Energy Exertion Analysis of Ridging Prototype

The women smallholder farmers who took part in the shimmer sensors' calibration tests conducted ridging tool tests and make twenty turns with each tested tool. The sensors captured data for each of women which was used along with user profiles and other data to determine the energy exerted for each tool tested. Energy differentials are presented in table 5.2 below:

Table 6-5: : Energy Exertion Co-Designed Ridging Hoe and Existing traditional Size Hoe

Handles for Ridging hoe Tool Trials	**Average Energy (KJ)** 20 turns for each tool tested
New Long - LN	9283380.05
Existing Long- LN	6853222.22
New Long - WR	8835919.55
Existing Long - WR	6195448.45
New Medium - LN	**8310835.69**
Existing Medium - LN	9941493.94
New Medium - WR	**7717372.34**
Existing Medium - WR	9183961.86
New Short - LN	7036139.51
Existing Short - LN	5749759.77
New Short - WR	6612565.61
Existing Short - WR	5205011.79
Sig.	**0.63**

The table above show the mean comparison of energy that is used when using old and new hoes with different handle lengths (short, medium and long) as well as wide range (WR) and low noise (LN) conditions. The results indicate that there are no significant differences in energy used in all the ridging hoes as shown by the P.value >0.05 (0.63). This indicates that there were insignificant differences in energy input when using the improved and old hoes of different handle length sizes and type. However, there were some energy savings demonstrated for the new prototype when using the medium handles that were one meter long. Considering the challenges noted below during the trials, it is possible that with these factors kept constant, the new tools may have demonstrated even higher energy savings.

The tool has the same shape and size as the existing traditional size hoe. However, this tool is different from the existing hoe sold in Malawi because it has a fixed handle to blade connector. The new prototype is slightly lighter than the existing hoe as the women indicated that the existing one is a little too heavy for them when ridging. The activity requires them to carry soil using the hoe, making it heavier than it already is. Qualitative feedback from the women smallholder farmers was that this tool is an improvement to a tool that worked well enough for ridging but was a little heavier and not safe to use. According to the women smallholder innovator groups, with the new improvements, this tool is market ready and would do extremely well.

6.4.3 Energy Exertion Analysis of Planting prototypes

Sasakawa Prototype

For the planting trials, the women farmers tested the Sasakawa co-designed prototype against the existing two to three-year-old traditional hoe available in Malawi. Farmers were asked the test both tools and make twenty turns for each tool they tested. Table 5.3.1 below presented the energy use analysis results.

Table 6-6: Energy Exertion Comparison Co-Designed Sasakawa Hoe and Existing Hoe

Sasakawa Hoe Handle Sizes	**Average Energy (KJ)** 20 turns for each tool tested
New Long - LN	1280727.90
Existing Long - LN	1502165.68
New Long - WR	**1200631.62**
Existing Long - WR	1316710.37
New Medium - LN	**1402526.49**
Existing Medium - LN	1758581.88
New Medium - WR	**1312593.42**
Existing Medium - WR	1549595.37
New Short - LN	**1080249.62**
Existing Short - LN	1183457.62
New Short - WR	**1019323.87**
Existing Short - WR	1056397.14
Sig.	**0.70**

Results above show mean comparison of energy that was used when using old and new Sasakawa hoes, which had different handle lengths (short, medium and long) and types (LN and WR). The results showed that there were no significant differences in energy used in all the hoes as indicated by the P.value>0.05 (0.70). However, the new tools demonstrated some energy savings when assembled with the any of the handle sizes. Considering the challenges noted below during the trials, it is possible that with these factors kept constant, the new tools may have demonstrated even higher energy savings. This finding also demonstrate that based on the assembly of the tool and ergonomic suitability, the user's energy exertion levels may increase or decrease as was seen during the trials. The new co-designed Sasakawa hoe showed less energy exertion during trials than the existing tools for the tested handles.

The qualitative feedback collected from the women smallholder farmers was that this tool can be refined slightly to make the blade longer and narrower in order make deeper plant stations. The tool is otherwise market-ready. This planting prototype is the smallest of the all the tools co-designed and produced for cultivation tool trials. The tool has a very small blade and handle that makes the tool extremely light and easy to carry using one hand. According to smallholder farmers who participated in the design sessions, this small tool is suited to the planting stations needed and frees up one hand to carry the seed to be planted. It was therefore the most preferred tool of all the tools tested.

Energy Exertion Analysis of Three-Blade Planter Prototype

The women smallholder farmers who took part in the shimmer sensors' calibration tests were asked to conduct planting activities and make twenty turns with each tested tool. The attached sensors captured the data for each of tested women which was used along with user profile and other data to determine the energy exerted for each tool tested. The energy differentials for the LN and WR ranges are presented in table 5.3.2 below:

Table 6-7: Energy Exertion Comparison - Three-Blade Planter and Existing Tool

3-Blade Planter Handle Options	**Average Energy (KJ)** 20 turns for each tool tested
New Long - LN	**3353235.65**
Existing Long - LN	3894826.55
New Long - WR	**3139848.66**
Existing Long - WR	3578042.51
New Medium - LN	**1085353.87**
Existing Medium - LN	3398989.99
New Medium - WR	9904004.76
Existing Medium - WR	**2879058.50**
New Short - LN	**1469931.05**
Existing Short - LN	6307561.73
New Short - WR	**1455286.48**
Existing Short - WR	6077755.60
Sig.	**0.07**

Results above show the mean comparison of energy that is used when using old and new 3-Blade Planters with different handle lengths (short, medium and long) and types (LN and WR). The results indicate that there were no significant differences in energy used in all the hoes as shown by the P.value. >0.05 (0.07). However, the new tools demonstrated some energy savings when assembled with the long and short handles.

Considering the challenges noted during the trials, it is possible that with these factors kept constant, the new tools may have demonstrated even higher energy savings. This finding also demonstrates that with additional refinements, the new tool may demonstrate higher energy savings. This planting prototype is a combination of three blades and was co-designed with the intention of making more than one planting station at a time. It has three small blades attached to a single handle as well as much smaller "marker" blade to indicate where the next planting station should be placed. The co-designed 3-blade planter showed much less energy exertion during trials than the existing tools and recorded the least amount of turns per tool to make planting stations.

Type of Test	Number of Prototypes	Existing Tools	Energy Analysis	User (Tester) Feedback
Land Clearing	Curved Edge, & Grated	Traditional hoe (3 -5 yrs. old)	The curved hoes and wide blade hoes performed better than the existing hoes on energy exertion to some extent. The clearing grated hoe performed the best for the long handle option. The clearing curved hoe performed well when using the medium handle.	Remove the grates and have a flat blade to clear better. Remove the "windows and have a full blade like the weeding tool to increase the tool's life span and durability.
Ridging	Ridging Hoe	Best 43 Hoe	New tool takes, on average, less energy than Best 43 Hoe, when using the medium handles.	The hoe is perfect and ready for the market. Farmers preferred it to the existing hoe as it has the handle-blade fitted connector.
1-seed Planting and 3 – Seed Planting	Sasakawa Hoe, & 3-Blade Planter	Small axe or hoe & Traditional hoe (3 -5 yrs. old)	The new small hoe performed better as compared to the 3-blade planter and existing tools (for all handle preferences). The 3-blade planter performed well compared to the existing tools when assembled with the long and short handle sizes.	The farmers would like the blades to be slightly longer and narrower, to make deeper planting stations. They otherwise like the tools.
Weeding	Straight Edge, & Flat blade	Traditional hoe (3-5yr old)	Unfortunately, due to the delays in getting resources and the tools produced, there were no available weeding plots to test the prototypes against the existing tools. However, as this tool is similar to the clearing tools, the energy exertion outputs may be similar.	The farmers suggested to alter the design of the clearing grated blade to match the weeding flat-blade hoe as this would enable the tool to clear farm more efficiently and effectively (time and energy use is expected to be significantly reduced).

The qualitative feedback collected from the women smallholder farmers was that this tool is market ready as they liked the ability to make planting stations much faster than all the tools tested. They asked to remove the "marker" blade to make the tool lighter. Farmers indicated that this tool is ideal as they typically plant with other family members and can quickly complete this task with one member making multiple planting stations at a time and another dropping the seed and covering the planting station. Below table summarizes the energy exertion analysis results by activity and includes user feedback captured after each tool trial was completed using KIIs.

6.4.4 Final Prototypes Selected for Dissemination to Farmer Groups

Based on the findings of chapter 5 and 6, on time differentials and energy exertion levels combined with key end-user feedback, the research selected the tools that demonstrated any time or energy savings that were specifically selected and preferred by the women farmers based on the qualitative feedback received on ergonomic suitability and other parameters explained in the methodology sections. .

The research objective at this point was to delivery these sets of improved tools to each woman innovator to be further tested over the next farming season. The objective was to conduct long-term on-farm trials on the women's own farms over a period of one year. The full overview of this process is captured in chapter eight. The women smallholder farmers were engaged at every stage of the labour saving participatory technology development process over the four-year research period. The time inputs of the women farmers have been meticulously documented and the women innovators received these toolkits as a payment in kind for the opportunity cost of the labour and time that each of them contributed during their participation in the design, testing, refinement and final production of these tools.

Figure 6-2: Mass Produced Tools for further testing by Women Farmers

6.5. Discussions and Conclusions

The key informant interviews provided valuable insight regarding the opinions of the women's innovator groups during the energy exertion trials. They prefered the newly designed tools as they were lighter, had the handle-blade connector that made the tools safer and in general, more ergonomically suitable for the users. The users noted that they made fewer numbers of turns on average for the new tools as compared to the existing tools. During the trials, this research demonstrated that wearable kinematic sensors when utilized accurately, can provide opportunities for indirectly measuring energy exertion for different human movemements, including agricultural tasks. Although the energy savings demonstrated were not statistically significant, considering that these were experimental tests using kinematic sensors tailored to the sports sector and not the agricultural tools, the improved tools demonstrated some potential to save time and energy for the end-user which ultinately is the desire of the smallholder farmers.

It should be noted that there were several challenges during the trials that may have compromised the outcomes of the energy exertion tests and this must be taken into consideration when reviewing the results presented above. These included:

Shimmer Settings: a key challenge was that it was not possible to change the data capture intervals to increase the accuracy of the energy use approximation. The shimmer support team were not able to assist and indicated that the software may have had some limitations or may have been faulty. It was not possible to procure additional ones due to resource limitations.

Data Upload requirements to work in the field: Testing of the shimmer kits revealed a key challenge for developing countries such as Malawi. The assumption was that with fully charged shimmer sensors, data collection in remote field locations would be possible with the expectation that the captured shimmer data could be transferred to research laptops at the end of each on-farm tool trial day. However, the shimmer sensors were not programmed to collect data continuously without regular upload. The shimmer procedures required that the sensors get docked after every test, and the data recovered in between every test.

Low battery life: The tool trials typically took a full day to be completed. A key challenge was the low battery life that the sensors had, which forced the trials to be terminated prematurely. As a result, the tests took slightly longer to complete. The research ensured charged the sensors on a daily basis to reduce these bottlenecks during the on-farm trials of the new prototypes and existing tools. Ideally for future research, it would be advisable to have back up battery packs where possible.

Flashing lights on sensors: The sensors' lights were difficult to see during the field trials when there was hot bright day. This caused some errors and repetition of tests to avoid compromising the data accuracy. A recommendation was made to tailor the design of the sensors to be better suited to on-farm trials.

Sensor safety: During the pre-testing trials, the shimmer sensors frequently got dislodged from the tools every five meters on average. This was because the attachment belts that were on the sensors were not designed to withstand the rigorous movements that are associated with manual farming in a farm with lots of left-over stubs from the previous farming cycle, grass, and hardened soil. Various methods of reinforcing the attachments were explored, and as a contingency measure, the research supported the sensors bands with elastic rubber bands with the expectation that these would withstand the tool to ground impact. The sensors and accessories could potentially be refined and customized to work in on-farm applications as well as for other outdoor testing requirements.

Considering the challenges noted above, the time and energy savings captured may potentially have been much more significant if the technical issues were absent. A key lesson learned using the Shimmer sensors is that the instruments applied must be adapted for on farm testing considering the challenges noted above. A follow-on research on this would add value to this discussion in the future. In addition, as indicated above, all the women's innovator groups highly expressed their preferences for the newer tools as they were lighter, more contemporary and customized and in general, were safer and better tools to use. The research envisioned that based on the feedback from the women innovator groups and their use of the disseminated tools to be explained in chapter 8, the demand for improved agricultural tools may increase. It was therefore important to assess the current markets for handheld agricultural tools in the research areas and evaluate consumers' willingness to pay for improved labor-saving tools. To collect insights from market actors, an in-depth market assessment was conducted to better understand the consumer preferences for the improved tools. Chapter 7 provides an in-depth summary of the market assessment conducted for the produced hand-held agricultural labor-saving tools.

7. CHAPTER 7: MARKET REVIEW OF HAND-HELD AGRI-TOOLS IN MALAWI

7.1. Background

As detailed in earlier chapters, this PhD research was able to successfully test the hypothesis that women farmers have the capacity to co-develop and test the prototypes for the cultivation and post-harvest seasons. With this evidence base of labour-saving tools, the research embarked into a market scoping study to assess the viability and existence of markets for the newly produced women farmer co-designed hand-held agricultural tools. This study would form the basis for any institution interested in taking up the distribution and promotion of labour-saving tools in Malawi or other similar settings.

7.2. Research goal and objectives

The specific research objectives of the market research were to identify the current market opportunities and challenges for scaling-up production and dissemination of the hand-held and post-harvest labour-saving tools. The market study aimed to identify:

- *The value chain actors for hand-held agricultural tools in Malawi*
- *Available markets for the improved hand-held agricultural tools*
- *Critical pricing, product and placement/customer purchase points.*

7.3. Research Methodology

The research was conducted with rural communities in Lilongwe District- Kabudula and in Kasungu District- Nkhamenya where the innovator groups are located. The market assessment focused on markets surrounding the sampled farmers and aimed to reach at least 5 different districts that surround the core research bases.

7.3.1 Sampling Frame and Survey Design

This survey considered the supply component i.e. the actors involved in the supply and dissemination of hand-held agricultural tools as well as the demand component i.e. the number of farm households who are willing to purchase labour-saving agricultural tools. Data was collected from other “actors” who play a crucial role in the improvement of access to and adoption of quality and labour-saving hand-held agricultural tools.

The following groups were included in the market assessment exercise:

Smallholder farmers: Male and female farmers were interviewed using a structured questionnaire that was translated into Chichewa, the local language. Where necessary, content was translated into Tumbuka, a language more frequently used in the Northern region of Malawi.

Government Extension Workers: The research collected data from government agricultural extension workers based in various extension planning areas (EPAs).

Retailers and Local Tool Producers: As these target groups either directly produce the hand-held agricultural tools or purchase tools for resale, their opinions were crucial and were included during the survey. All interviews were conducted with individual open-air market vendors, hardware shops and retailers of hand-held agricultural tools.

Non-Governmental Organizations: FGDs were used to capture the views of organizations that are either directly implementing labour-saving initiatives or those who provide access to labour-saving initiatives.

Carpenters and Vendors of Timber: Key Informant interviews were also conducted with these groups to capture and compare production rates for tool handles as well as production rates hand-held agricultural tools in Malawi and other countries.

7.3.2 Gender Division of Target Groups.

Disaggregated gender analysis was conducted to ensure that the data collection was completed using an inclusive approach from which an equitable distribution of responses among women and men could be achieved where possible. The gender differences of AEDOs who were interviewed during the study were 48.90 per cent males and 51.10 per cent females. Fifty one percent of the smallholder farmers were male while 49 were females. The retailers were dominated by males (81.10 per cent) than females (18.90 per cent). Lastly respondents from NGOs and FOs consisted of 76.70 per cent males and 23.30 per cent females.

Table 7-1: : Summary of Gender Distribution the Target Groups

	AEDO	**Smallholder farmers**	**Retailers and Tool Producers**	**NGOs**
Gender Differences	**Frequency of Responses%**			
Male	46 (49%)	52 (51%)	77 (81%)	23 (77%)
Female	48 (51%)	50 (49%)	18 (19)	8 (23%)

7.3.3 Survey Design

A structured questionnaire was designed to collect data from each target group described above. The questionnaires were designed to be delivered in person and in local dialect to the smallholder farmers and some of the retailers. The Government/Extension Workers and NGOs staff completed the survey in English in person or via email. Telephone conversations were applied where email and in-person interviews were not possible. Please refer to the appendix section for the 4 designed questionnaires and guiding questions for the focus group discussions.

7.3.4 Pre-Testing of Research Materials

The surveys were pretested by the research team with local farmers and retailers at the Chitedze Research Station and around Lilongwe city. Further pre-testing was conducted in the field. Based on the pre-tests, revisions were made to each of the four survey questionnaires before dispatching the research team.

7.4. Results

7.4.1 Predominant Tool Used by Smallholder Farmers in Malawi

A diverse group of respondents were successfully interviewed and were asked to identify the existing tools that are available for cultivation season activities in Malawi. Respondents included: smallholder farmers (n=102), retailers (n=95), AEDOs (n=94) and NGOs (n = 31).

Table 7-2: Existing Agricultural Tools Identified as Most Commonly Used Tools

Type of Tools	**Land clearing**	**Ridging**	**Planting**	**Weeding**
	Frequency (%)			
Hoes	101 (99%)	101 (99%)	56 (54%)	102 (100%)
Slashers	1 (1%)			
Ridger		1 (1%)		
Hands			17 (16%)	
Small hoes			26 (25%)	
Sticks			3 (2%)	
	102 (100%)	102 (100%)	102 (100%)	102 (100%)

Results from all respondents indicated that the most commonly used tool for all farming activities is the hoe. Such " traditional " hoes are the only tool available in stores and at local vendors and are sold as a "one tool fits all". Discussions with shop owners and vendors reveals that these tools are the ones that they have access to for sale and farmers purchase what they find rather than what they actually need for the specific tasks in the farm.

7.4.2 The Need for Improved Hand-Held Tools in Malawi.

To assess the level of need for improved hand-held agricultural tools for smallholder farmers in Malawi, a question in each survey instrument (questionnaire and checklist) asked respondents to assess the level of need for improved hand-held agricultural tools for smallholder farmers. Results from the different groups of respondents indicate that the majority of respondents consider smallholder farmers in Malawi to have a **high need for improved hand-held agricultural tools** for their farming activities; land clearing, planting and weeding; which are considered to be labour intensive.

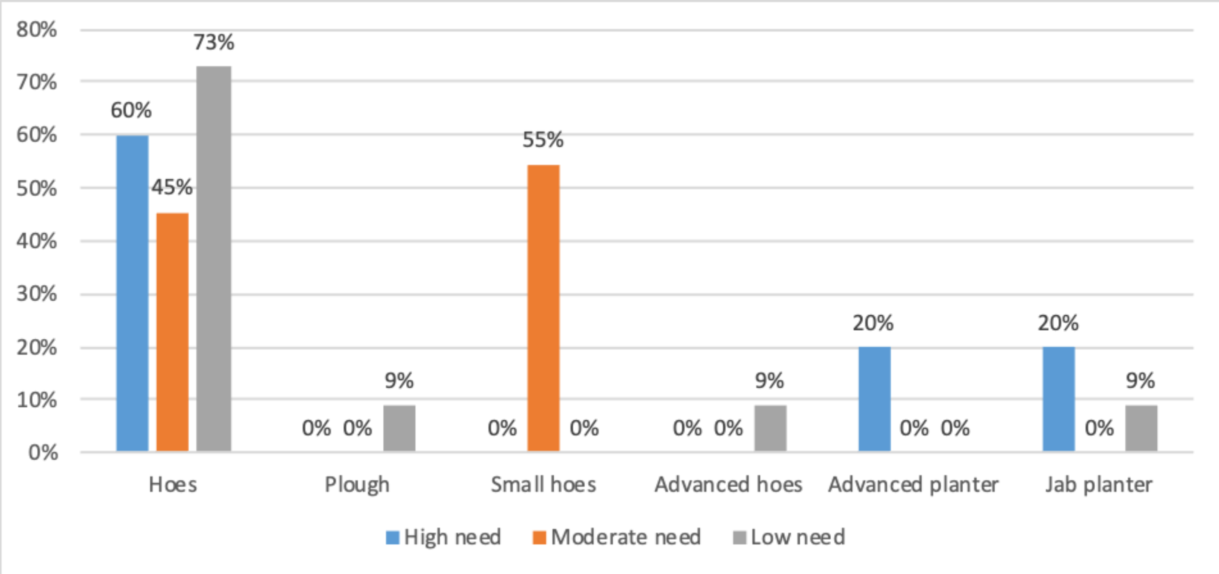


Figure 7-1: Ranking of improved tools needed for Planting.

During planting, the highly needed tools included the improved hoe (60 per cent), the advanced planter (20 per cent) and the jab planter (20 per cent). The small hoe was also mentioned as a moderately needed tool (55 per cent) followed by the traditional hoe (45 per cent).

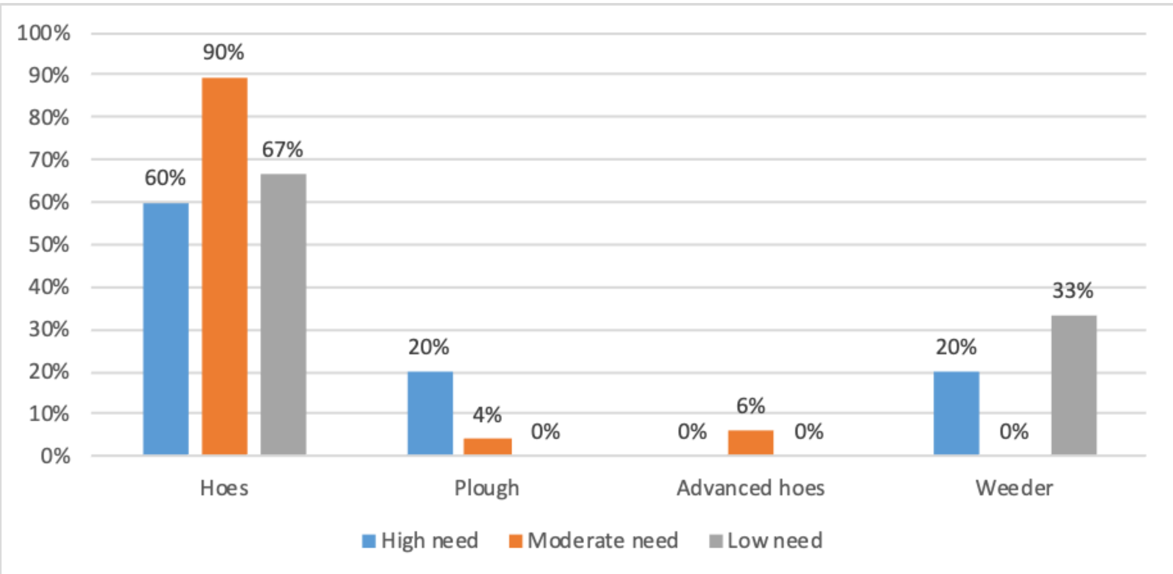


Figure 7-2: Ranking of tools needed for weeding

The highly needed tool during the weeding period was the improved hoe (60 per cent), followed by the plough (20 per cent) and the weeders (20 per cent).

7.4.3 Common Consumers of Hand-Held Agricultural Tools.

Most of the retailers and local producers who were interviewed indicated that male and female farmers were the most frequent buyers of their hand-held agricultural tools for all farming activities in the cultivation season (95 per cent). There were over 70 per cent of responses coded as "no response" for the "occasional", "rare" and "Never" response options for all farming activities; land clearing, ridging, planting and weeding. This could be a result of the retailers' and local producers' lack of training in customer information management which is reflected in their inability to distinguish between various classifications of customers as they typically do not record or collect any information other than their contact details. Of those who did respond, female farmers and construction companies were listed as the occasional buyers of the hoe for land clearing in the surveyed parts of Malawi. They noted than in the last two years, there have been increasingly more women purchasing tools than men. This indicates that there could be possible reasons why more women are participating in the acquisition of farming tools for their households, such as:

- Increase in female-only headed households (due to deaths or work-based migration of males)
- Increase in women's participation in decision making on purchase of assets
- Increase of women's role in production of commercial and food crops for the household
- Increase in women's disposable income.

7.4.4 Household Labor Division in Purchase of Farming Tools

Smallholder farmers were asked to indicate who in the household typically purchased agricultural tools. Based on the respondents, males are the household heads and do most of the tool purchases (52-55 per cent based on activity the tool will be used for). While there were a significant number of cases where both partners purchased the tools (32 per cent), few respondents indicated that it was the wife who purchased the tools (10 per cent). While there were some respondents (1 per cent) who indicated that they sometimes sent their sons go to purchase farming tools, no respondents indicated that their female children purchase farming tools on behalf of the household. This indicates that purchase of farming tools is still widely viewed as mainly a male role in the household.

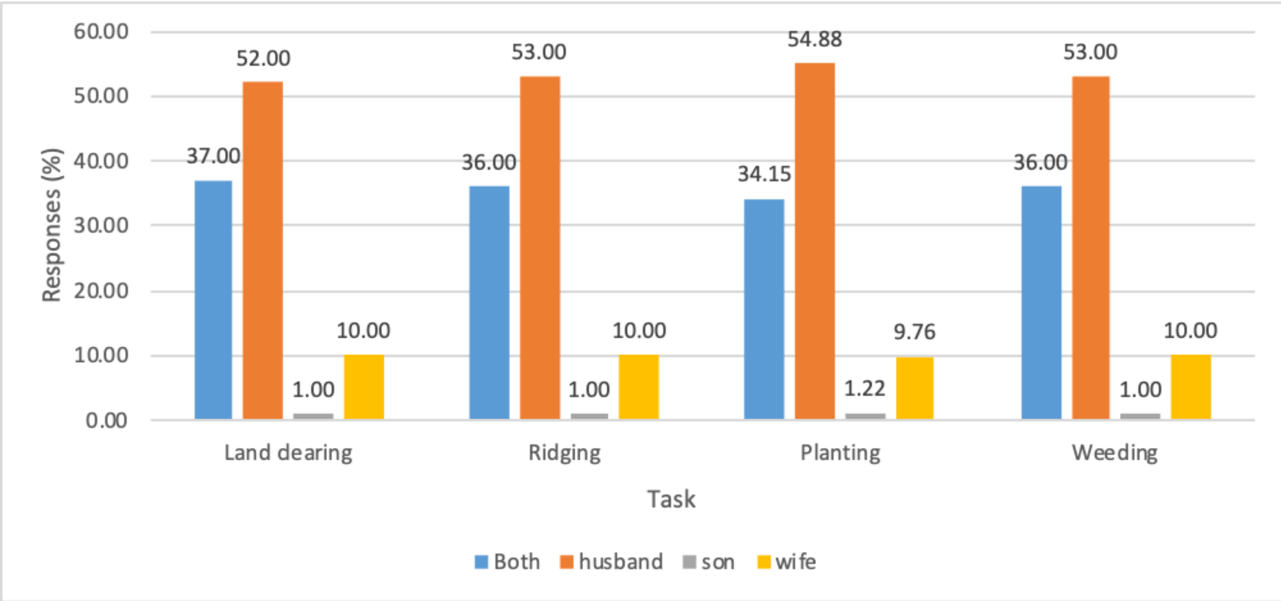


Figure 7-3: Household labour division on purchase of agricultural tools.

7.4.5 Most Common Purchase Points for Farming Tools in Malawi

The figure below indicates the most common purchase points for the land clearing and ridging tools as identified by smallholder farmers in 5 districts of Malawi. Farmer's world and market vendors were identified as the most common tool purchase points.

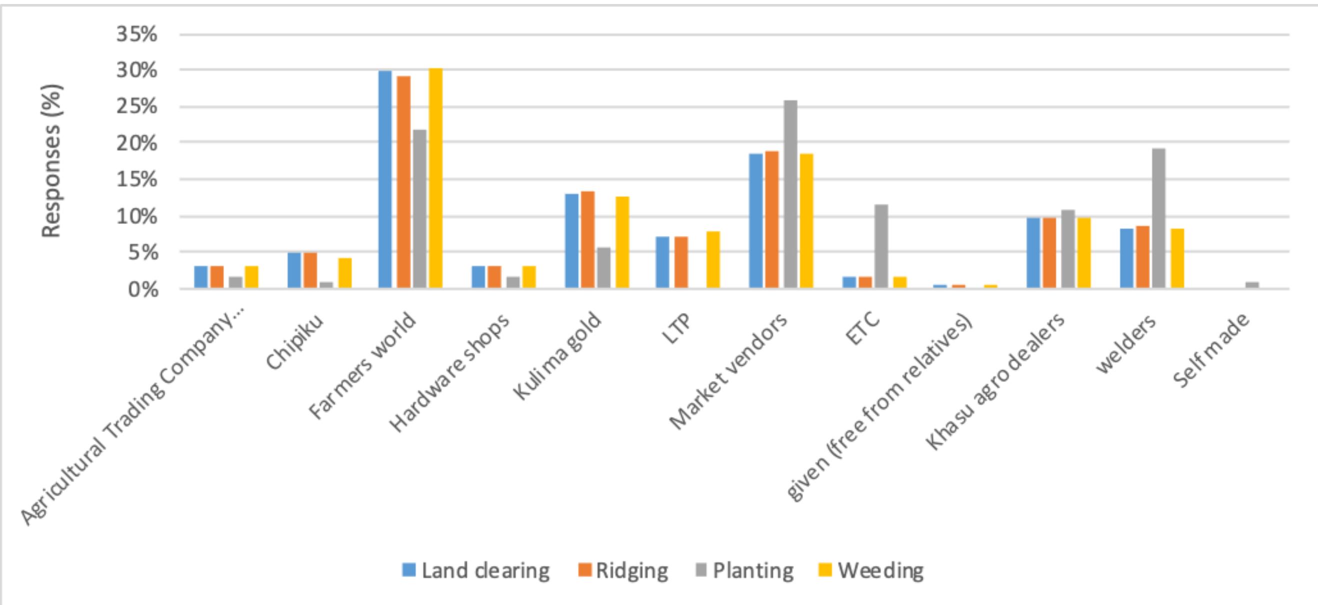


Figure 7-4: Smallholder Farmers' Most Common Purchase Points for Tools

In addition, 102 surveyed farmers indicated that the only hoe sold at most vendors is the traditional size hoe, which through this research has been identified as the most suitable hoe for ridging but not for the other labor-intensive tasks (refer to chapter 3 page, 85). Respondents indicated that the ridging hoe is larger/heavier than the tools preferred by women smallholder farmers.

7.4.6 Analysis of Prices of Hand-Held Farming Tools in Malawi

Comparisons of existing and new improved tools yielded slight differences in prices for all tools and results of discussions with farmers indicate a willingness to pay higher prices for better quality tools. The figure below shows the average price differences in local currency, Malawian kwacha (MK).

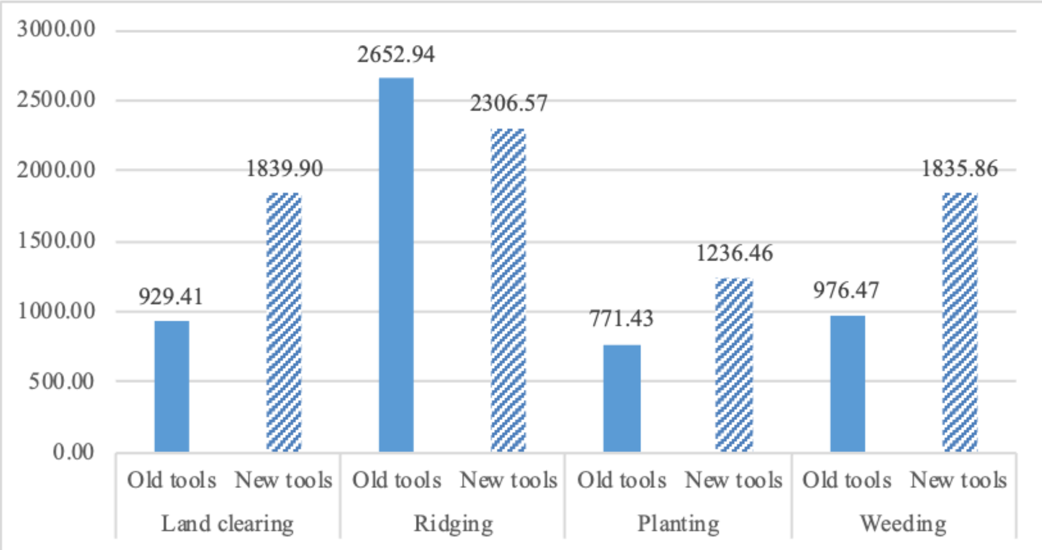


Figure 7-5: Prices of new and existing farming tools.

7.4.7 Pricing Fluctuations of Hand-Held Tools by Season

The figure below shows the breakdown of prices of hand-held tools with respect to the month. Based on the results, August, September and October were the peak periods for selling farming tools.

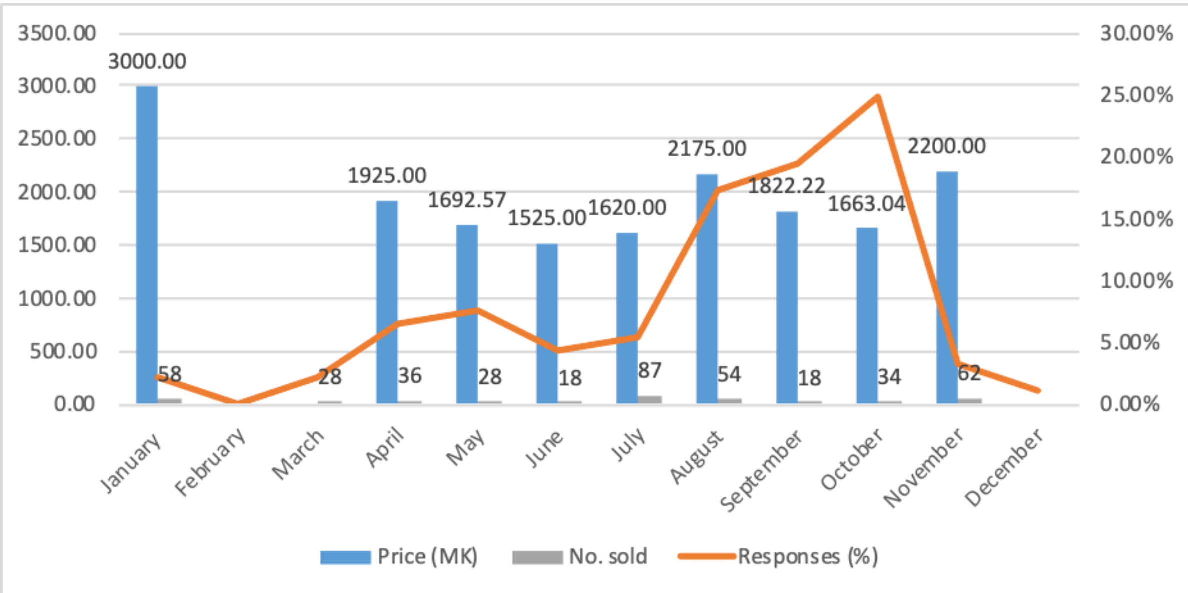


Figure 7-6: Seasonal Prices of Hand-Held Farming Tools as per Retailers and Tool

A key finding is also that the current price of the hoe is still very similar compared to when the initial resource and market mapping was done in 2014. This is although the local currency has dropped from MK420.00 to US$1.00 to around MK745.00 to US$1.00 now[1]. While the foreign exchange continues to weaken, the income levels of the smallholder farmer has remained the same. As prices of items have increased to account for inflation and changes in producer prices, the cost of living is now much higher while the disposable income is now much less.

7.4.8 Smallholder Farmers' Willingness to Pay

Smallholder farmers specified what improved tool they preferred to have for each farming activity and indicated the price they were willing to pay for each. Table 6.9.1 below shows specific prices that smallholder farmers are willing to pay for improved farming tools for the cultivation activities.

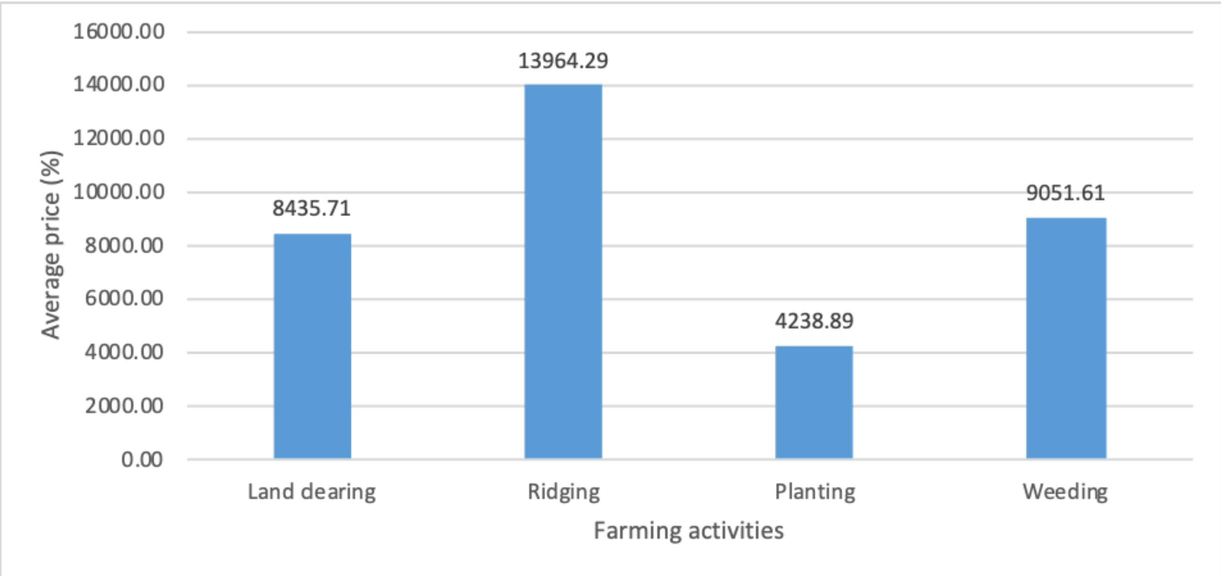


Figure 7-7: Pricing Smallholder Farmers are willing to Pay for Improved Tools

Market assessment conducted with smallholder farmers in various parts of Central and Northern Malawi reveal a range of prices that farmers are willing to pay for improved hand-held agricultural tools for their farming needs. Most of the farmers did not respond to questions related to type of tools needed for land clearing. However, out of the respondents who did indicate tools they need and how much they were willing to pay, majority indicated that they would be willing to pay between 800MWK and 5000MWK for an improved clearing tool. This is equivalent to a price range of US$1.08 and US$6.80.

A range of prices were indicated by each smallholder farmer and cross-referenced with the kind of tool they indicated they needed for the ridging activity. From the table below, 80 per cent of the farmers who indicated a willingness to pay for tools were willing to pay between MWK500.00 and MWK10,000.00,

[11] https://www.rbm.mw/Statistics/MajorRates

with 68 per cent willing to pay from MWK500.00 to MWK5,000.00. This is equivalent to an estimated price range of US$0.67 to US$13.42 on the higher end and US$0.67 to US$6.71 for the lower end. This is within the range of current new and used prices for tools as identified by smallholder farmers and retailers.

Price ranges for planting hoes were much lower as these are typically smaller and lighter and even more importantly for price considerations, are made by local tool produces who use cheap scrap. Based on feedback provided, an estimated 20 per cent indicated willingness to pay prices ranging from MWK250.00 to MWK 2,000.00 for improved planting hoes. This is equivalent to US$0.34 to US$2.68. This is within the range of current new and used prices for tools as identified by smallholder farmers and retailers in the above sections.

Similar to the planting tools, the traditional size was identified most frequently as the type of tool used for weeding. Farmers' willingness to pay price ranges for improved weeding hoes was similar to the ridging analysis above. Based on feedback provided, an estimated 53 per cent indicated willingness to pay prices ranging from MWK 200.00 to MWK 5,000.00. This is equivalent to a US price range of US$0.27 to US$6.71. This is within the range of current new and used prices for tools as identified by smallholder farmers and retailers in the above sections where price point results have been displayed.

7.4.9 Market Prices of Hand-Held Farming Tools

Retailers and tool producers were asked to indicate their sales of hand-held agricultural tools by farming activity during the cultivation season. Table 7.4.8 below shows the prices of tools by farming activity. Overall, retailers stated that prices for tools are at an average price of 1758.61, and with respect to tool type based on task, the prices were not significantly different as indicated by a P.value 0.92.

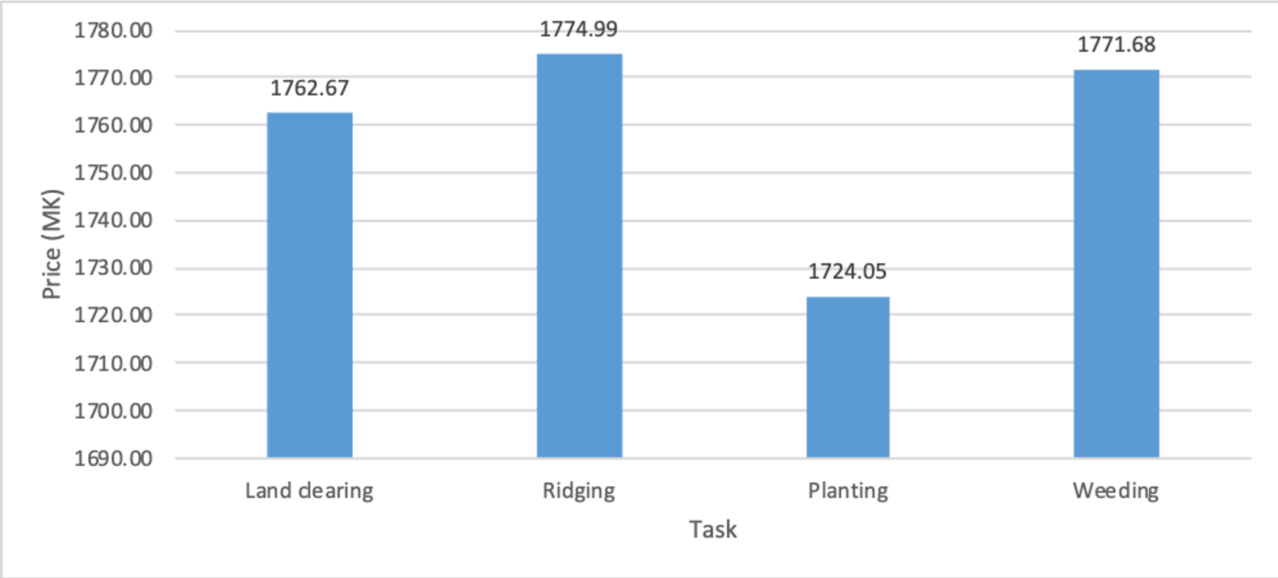


Figure 7-8: Retailer Prices of Tools by Farming Activity and Season

This is equivalent to US$2.50 in the peak season and US$2.00 in the off-peak season. This is within the price range identified by smallholder farmers as well as agricultural extension development officers in earlier sections of this research working report.

7.4.10 Changes in the Producer Base of Agricultural Tools

Retailers were asked to reflect on the past five years and identify any changes in the types of producers or manufacturers of hand-held agricultural tools in Malawi. This information is crucial in the market assessment as it also highlights the reasons for the changes in the producers of these hand-held agricultural tools, what these changes were and the reason for the change. Retailers gave their feedback on changes in the producers of the hand-held hoe, as this the most common tool used by smallholder farmers and the most popular tool (based on retailer responses) as indicated in results above as well. Table 7.2 below shows the breakdown of retailer responses.

Table 7-3: Changes in Producers for Hand-held Agricultural Tools

Changes noted	Frequency (%)
double	8 (9%)
about half	17 (18%)
seldom change	10 (11%)
no change	59 (63%)

An estimated 8 per cent of the retailers felt that the kind of producers for the hand-held hoe has completely changed in the last five (5) years, 17 per cent observed about half of the producer base is new while 59 per cent of respondents indicated that there has been no change in the producer base.

7.4.11 Monthly Summary of Sales of Agricultural Tools.

To investigate the slowest and busiest times for selling hand-held agricultural tool among retailers in Malawi, two questions were asked to respondents to 1) indicate their busiest months for the sale of hand-held agricultural tools and 2) indicate the most popular tool among smallholder farmers based on which tool was sold the most. Respondents were retailers and tool producers (n=95). The figure below indicates that January, February and March are the high business times, April May June and July are the moderate business times and lastly August, September, October, November and December are the low business times of the year.

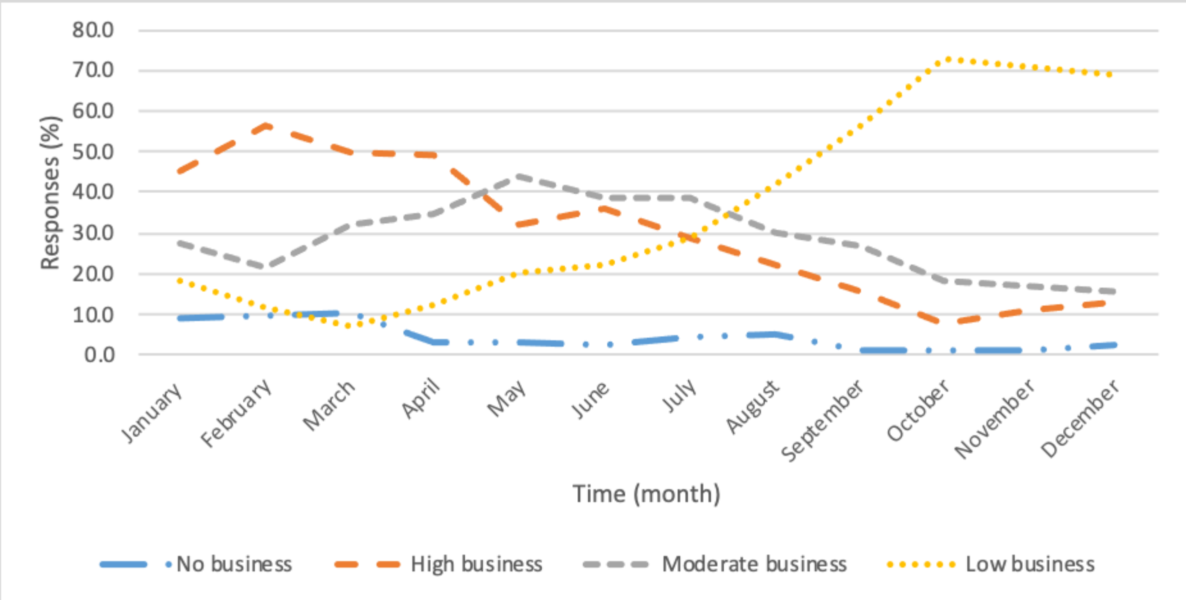


Figure 7-9: Ranking of Busy Months for sales of Agricultural Tools

7.4.12 Comparison of Changes in Agricultural Tools

Interviews that involved retailers and tool producers were conducted to compare the type of changes in tool design and quality respondents noticed oved the past five years. Retailers and Tool Producers responses highlighted the changes in tool design, what these changes were and are now. The results show that very few of the respondents observed complete changes in tool designs (8.51 per cent) and the majority (62.77 per cent) stated that there were no design changes in tools. A small proportion of the respondents stated that they observed changes in tool quality (11.70 per cent, with a majority (56.38 per cent) of the respondents having observed no changes.

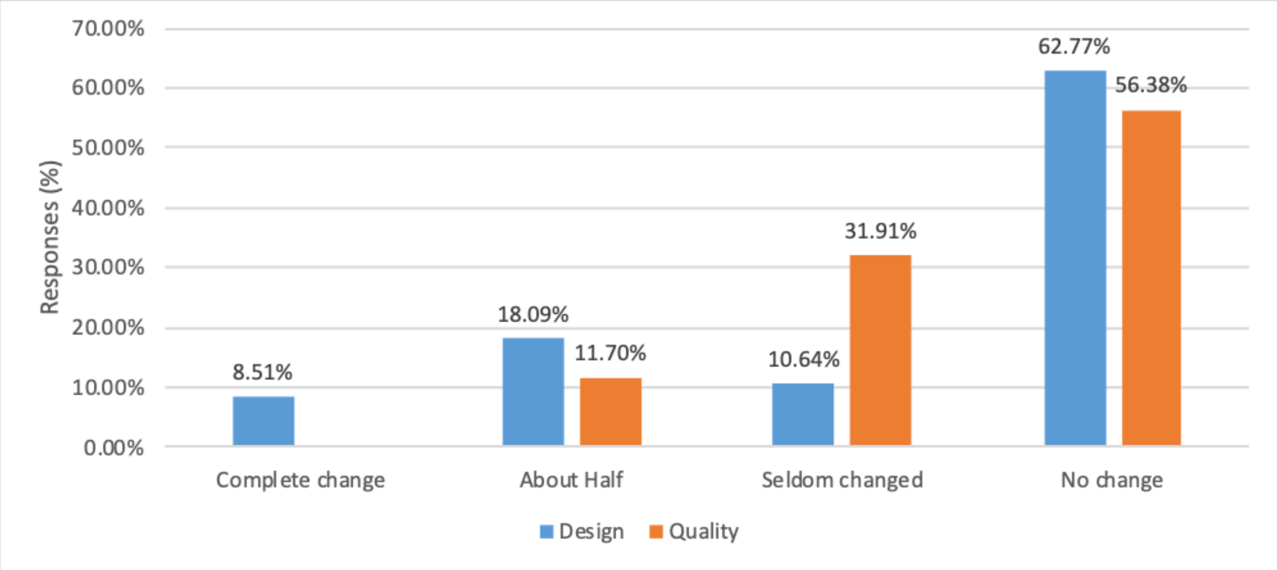


Figure 7-10: Changes in the design of hand-held agricultural tools in the last 5 years.

Types of Changes in the Design of Hand-Held Tools

Very few of the respondents gave specific details on the changes in the design of hand-held tools over the past 5 years. Those who did respond indicated that:

- The tool handle has been changed from wood to metal,
- The handle has become heavier
- The design of the hoe has become more curved now.

Reasons for Changes in the Design of the Hand-Held Hoes included:

- To improve handling ability as some handles broke due to the heavy blade-connecting pin.
- Customer preferences change over the years
- To improve durability of tools as locally and poorly made tools are available at lower prices
- Previous designs were harder to produce
- Exposure to designs from other countries like Mozambique

Comparison of Changes in the Quality of Hand-Held Agricultural Tools

Retailers and tool producers were asked to indicate whether there have been any changes in the quality of tools over the past 5 years and if applicable, what those changes were. Of the 93 respondents, 56 per cent felt that there are been no change in the quality of the hoe as an agricultural tool. However, 32 per cent indicated that although it was seldom, there have been some changes in the quality of the hoe. There were no respondents indicating complete changes in the quality of tools (the traditional hoe). About 12 per cent of the retailers who responded to the survey questionnaire indicated that the quality has improved by about half.

Changes in the Quality of Hand-Held Agricultural Tools in the Last 5 Years

- Tools are not as durable as tools produced in previous years.
- There are more than one type and quality of hoe due to many producers entering the market.

Reasons for Changes in the Quality of Hand-Held Hoes

- Low quality tools are produced as it is based on whatever material is available.
- Replicas of better-quality tools are imported and sold at much cheaper rates.
- Lack of quality assurance during production leading to low-quality tools in the market.
- Increase in demand for tools causing producers to focus on quantity & not quality.

7.4.13 Changes in Sales of Agricultural Tools

Respondents indicated their responses to questions regarding any changes in the amount of sales of hand-held agricultural tools in Malawi over the past 5 years. Retailers gave their feedback on changes in the sales amounts of the hand-held hoe, as this the most common tool used by smallholder farmers and the most popular tool (based on retailer responses) as indicated in results above as well. Reasons for Changes in the Sales of Hand-Held Hoes include:

- Retailers face economic problems causing them to supply less and get lower sales.
- Those who indicated an increase in sales stated that the reason for this was their good prices.
- Decrease in the demand for hand-held agri tools has led to a decrease in sales.
- Some of the respondents who noted an increase in their sales indicated that this was a result of their selling in bulk to offer lower prices (economies of scale).

7.4.14 Changes in Demand of Agricultural Tools

Some respondents indicated that the demand for hand-held hoes has increased (30 per cent doubled, 17 per cent about half, 9 per cent seldom change) over the last 5 years. Roughly 37 per cent indicated that the demand has actually did not change over the past 5 years. Further research on the quantitative changes through a review of financial statements, would add value to the market assessment in follow up research activities.

Table 7-4:Type of Changes in the Demand for Hand-Held Tools

Type of Changes	Responses
double	30 (32%)
about half	17 (18%)
seldom change	9 (10%)
no change	37 (40%)

Reasons for Changes in the Demand of Hand-Held Hoes

- Increase in the supply of quality hoes and higher demand from commercial farmers
- Changes in the customer base directly affects demand for tools.
- Economic problems forcing retailers to choose between supplying good quality tools in fewer quantities and get lower sales or supplying lower quality tools and make profit margin.
- Loss of customers who choose other retailers with better supply channels of good quality tools.
- Customers' product knowledge has increased, resulting in higher demand for better quality tools.
- Closure of some retail outlets resulting in more demand for tools at fewer outlets.
- Increased urban migration reducing number of people farming as employment/business.

Retailers indicated that they would be interested in marketing new tools that addressed the above demand concerns among retailers and users of tools in Malawi. These considerations on how to boost the demand for hand-held tools and on the other hand, how to strategize the business to avoid decreases in demand, are crucial for any retailers and local producers or marketers of improved hand-held agricultural tools.

Retailers were asked to specify exactly what type of changes they saw in the customers for hand-held agricultural tools in Malawi in the past five years. Table 7.3.1 below shows responses from 95 retailers in surveyed parts of Malawi. About 76 per cent of the respondents stated that there are new customers in the market as compared to 5 years ago. More specifically, 4 per cent respondents indicated that this change in customers is as a result of the increase in number of women farmers now as compared to five years ago. Other respondents indicated that NGOs are now purchasing hand-held agricultural tools for their beneficiaries while about 8 per cent noted that the change in customers was a direct result of some farmers shifting their focus to the construction industry for faster income generation. Further research on these changes would add value to the market assessment in follow up research activities.

7.4.15 Obstacles to Obtaining Improved Agricultural Tools

For any marketing strategy, a key component is the promotion of the product in a creative way that addresses the needs of the consumer. To effectively promote farmer-designed hand-held agricultural tools for the NUI Galway 3D4AgDev research, there must be a solid understanding of the smallholder farmers in Malawi and what challenges or opportunities the market presents. Smallholder farmers who participated in the market assessment exercise were asked to rank their biggest obstacles when trying to obtain improved hand-held agricultural tools in Malawi.

Table 7-5:Farmers Biggest Obstacles to Obtain Improved Agricultural Tools

Obstacles to Obtaining Improved Agricultural Tools	Frequency (%)
Price	104 (62%)
Knowledge of Tool	47 (28%)
Quality	16 (10%)
Reliable Brand Name	1 (1%)

Farmers indicated that they face significant obstacles when trying to acquire or gain access to improved or new technologies and tools. According to the data collected, the price of the tool was the biggest obstacle to obtaining new hand-held agricultural tools among smallholder farmers. Farmers also indicated that a lack of knowledge of the types of tools they should invest in also contributed to the lack of uptake of these improved tools. A small group of farmers ranked the lack of reliable brand names as a bigger obstacle than the availability of the tools themselves. Retailers of these hand-held agricultural tools need to be able to remove these obstacles to acquiring the ideal tools that farmers need.

For NGOs, farmer organizations, retailers and tool producers to support smallholder farmers to remove the key obstacles they face in access and adoption of an improved tool, several factors will need to be put in consideration. Price, knowledge, quality, brand name and availability of these new or improved tools are important to increase the likelihood of smallholder farmers to take up these new farming tools and technologies and adopt them in a sustainable and impactful way.

Factors That Hinder Smallholder Farmers Obtaining Hand-Held Tools (as per AEDOs)

AEDOs were asked to indicate and rank the top factors that hinder smallholder farmers from obtaining improved hand-held agricultural tools. Responses were in order of most hindering factor.

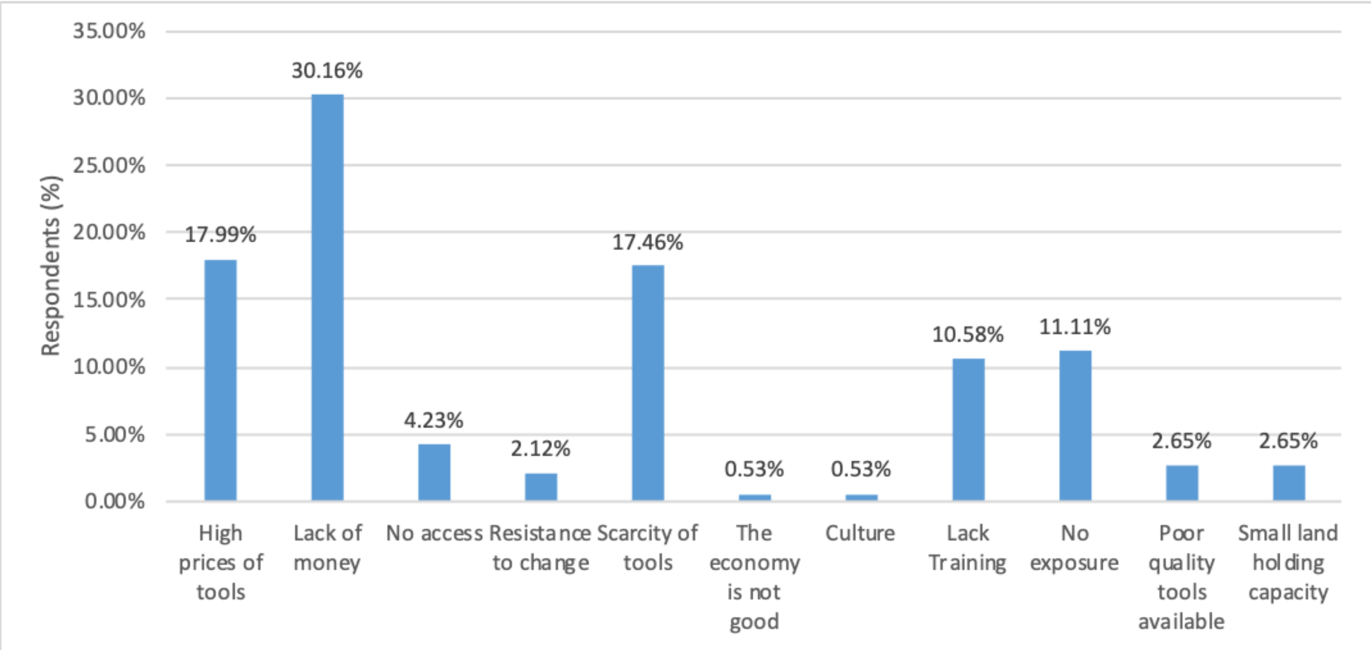


Figure 7-11: Factors Hindering Smallholder Farmers from Obtaining Hand-Held Tools

Responses from data collected indicates that according to AEDOs in Malawi, the biggest obstacles that farmers face when trying to obtain new and improved hand-held tools for their farming needs was lack of money, followed by high prices and scarcity of tools of tools. Factors ranked as 2nd most hindering were lack of exposure and lack of training

7.4.16 Criteria for Successful Adoption of Agricultural Tools

Smallholder farmers were asked to rank the criteria they consider most important for successful adoption of new agricultural technology/tools. Responses were in order of importance. Smallholder farmer responses indicate the most important criteria for successfully adopting new technologies or tools are*; 1) Addresses farmer's need, 2) Is readily available, 3) Produced by experts/engineers and transferred to farmers, 4) Produced through a farmer participatory process and 5) Labour-saving.*

AEDOs ranked the criterion they consider most important for successful smallholder farmer adoption of new agricultural technology/tools. Responses were in order of importance.

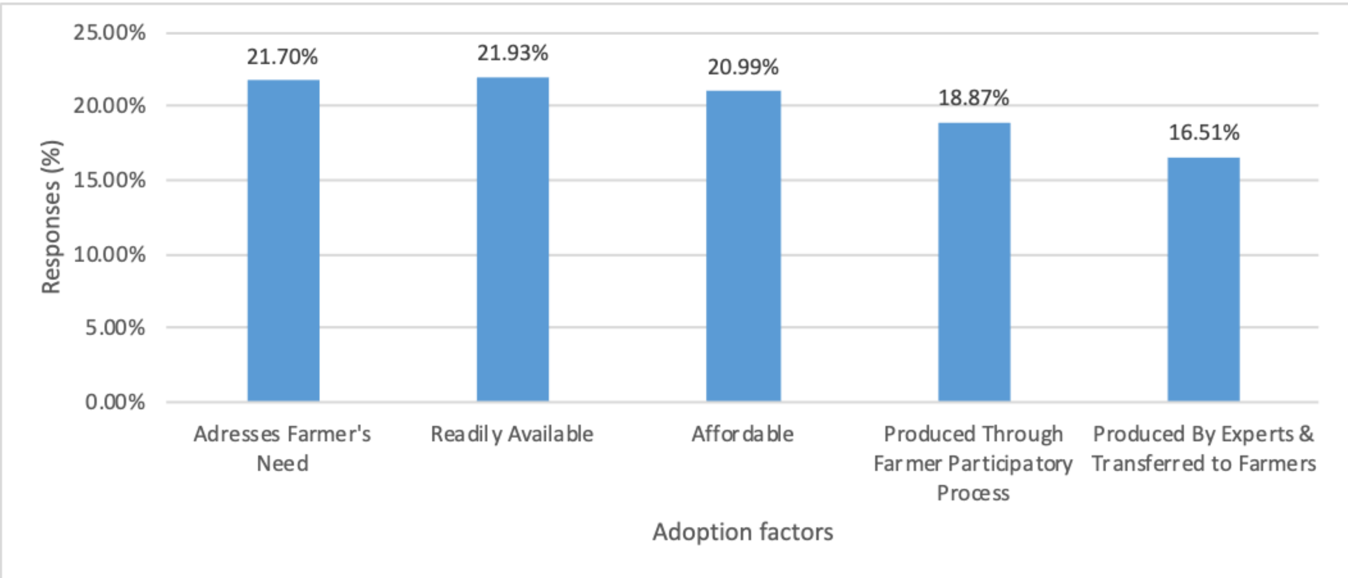


Figure 7-12: Factors for Farmers' Adoption of Improved Agricultural Tools

The highest factor that would support farmer adoption according to AEDOs is whether the tool addresses the needs of the farmer (21.7 per cent) and should be readily available (21.93 per cent). It is interesting to note, based on the market assessment responses, that while the agricultural extension services agents may think technology transfer is the second highest factor that can support smallholder farmer adoption, despite several efforts and initiatives in Malawi, there is no visible or sustainable uptake of any technologies by smallholder famers now because of technology transfer initiatives. Organizations supporting smallholder farmers also indicated the most important factors to consider for smallholder farmers to successfully adopt new improved hand-held agricultural tools. Table 7.6.3 shows the breakdown of responses from 31 NGOs and FOs.

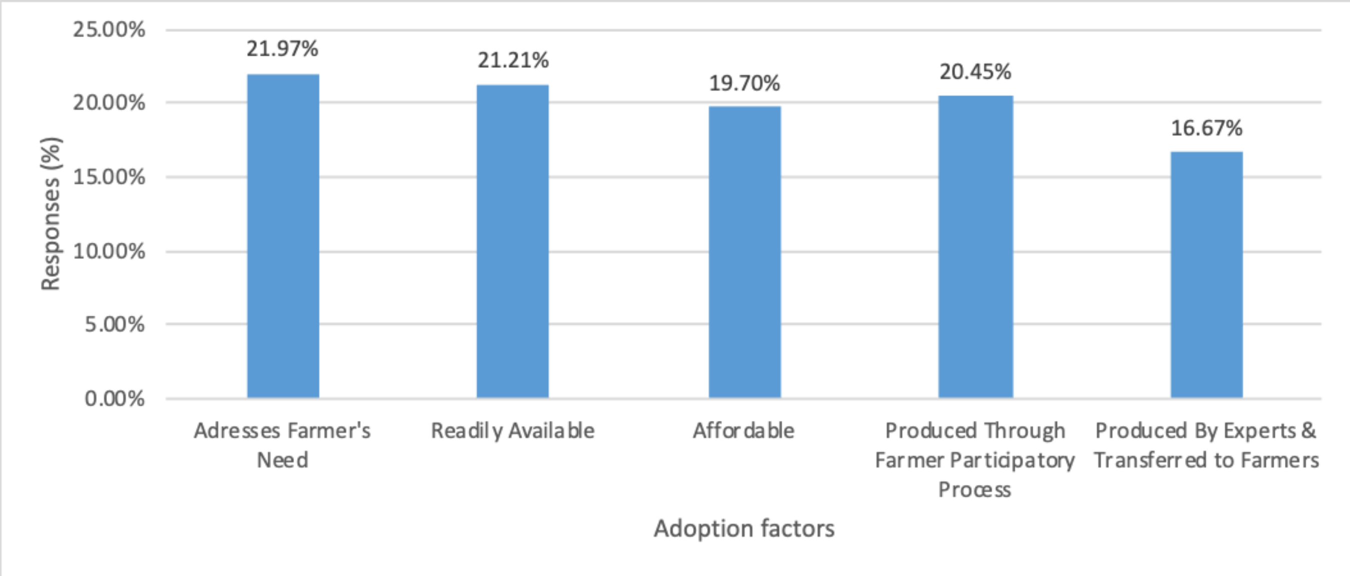


Figure 7-13: factors needed to successfully adopt improved tools

**** ETT (Expert produces tool and Transfers Technology)***
**** FPP (Farmer engaged in Participatory tool design Process)***

Factors that are important when identifying hand-held agricultural tools that can be successfully adopted by smallholder farmers were identified in order of importance from 1 to 5. The hand-held agri tool adoption factor with the ***"lowest*** average ***ranking"*** score i.e. out of 5, is the adoption factor ranked as the most important one for NGOs, farmer organizations, retailers and tool producers to consider when designing, producing, selling or promoting these tools to smallholder farmers. As farmers rely on NGOs, farmer organizations, retailers and tool producers to get access to information, tools and technologies, it is important to understand what the smallholder farmer considers important to them and what influences farmers to adopt technologies. According to NGOs and farmer organizations, the most important factor when adopting a new and improved hand-held tool/technology is whether the tool or technology adequately addresses the needs of the smallholder farmer.

Farmers typically rely on the expertise of the NGOs to guide them in selecting the right technologies and think of the NGOs as experts. This can perhaps explain why certain tools are more accessible than others and why farmers are adopting specific tools as they may be influenced by the NGOs who support them. This finding is confirmed by other authors (Glover D. S., 2016) (Andersson, 2014) who suggest that farmers' choices regarding agricultural technologies to adopt may be significantly influenced by existing support from NGOs and Government projects.

7.4.17 Criteria to Source Providers of Improved Agricultural Tools

Smallholder farmers involved in the survey ranked the criterion they consider when selecting hand-held farming tools for their activities. The lowest score represents the criteria listed as of highest importance. Rankings coded as 1= high importance to 5= lowest importance.

Table 7-6:Criteria that Smallholder Farmers' Consider when Selecting Hand-Held Farming Tools

Criteria that Smallholder Farmers' Consider when Selecting Hand-Held Farming Tools							
Adoption Factors	**Affordability**	**Quality**	**Labour -saving**	**Product Knowledge**	**Availability**	**Service follow up**	**Brand Name**
Average Ranking	1.53	1.72	2.32	4.00	3.17	3.20	3.67

Although customers trust known brand names, of more significance according to retailers when considering which service provider to select as the constant supplier of hand-held tools as they affect the profit margins, supply and resale value in addition to customer loyalty as they will search for more reliable purchase points that have good quality, well priced and well-designed tools.

7.4.18 Gender Considerations in Design & Production of Tools

All respondents assessed during the market survey (smallholder farmers, retailers, tool producers, NGOs, extension workers) were asked whether there should be any gender-specific considerations when designing agricultural tools and technologies. A majority of the respondents (44.83 per cent) indicated that the tools should be smaller and lighter than men's tools for the same psychical reasons. From the results of this study, it is shown that the weight, size and length of the handles of the are among the specifications that require consideration in designing tools.

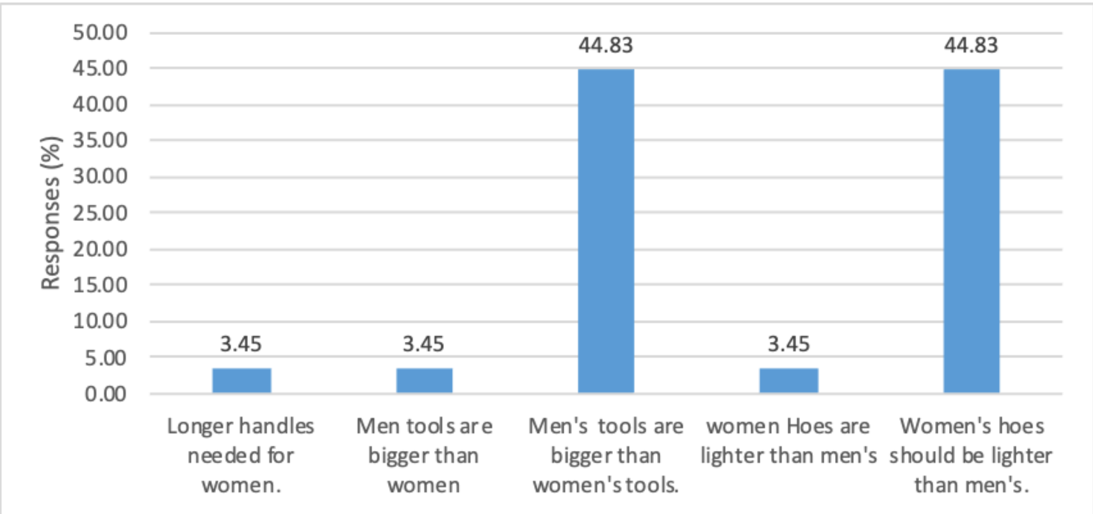


Figure 7-14: Gender Considerations in Production of Hand-Held Agri Tools

7.4.19 Key Informant Interviews with Carpenters and Vendors of Timber

Discussions with carpenters and timer vendors resulted in the identification of the right type of timber suitable for hoe handles. The most suitable type of wood based on resource mapping and interview data analysis, is the Blue Gum tree as this is readily available at both sites regardless of the recorded differences in access to natural resources in Central and Northern Malawi. The table below highlights the comparison of production rates for tool handles as well as production rates for metal cast tools that were compared.

Table 7-7:Average Tool Handles Production Estimates

Item	Cost/Unit	Quantity	Total Cost
Blue gum tree poles	€ 0.44	700	€ 310.95
Plaining and Smoothing of handles	€ 0.25	1400	€ 355.38
Handle-Blade assembly - labour	€ 0.25	1400	€ 355.38
Handle-Blade assembly - nuts & bolts	€ 0.38	1400	€ 533.06
Total			**€ 1,554.77**

Country Production Cost Comparisons for Cultivation Tools			
Tool Prototypes	**Unit Cost Ireland**	**Unit Cost Malawi**	**Unit Cost South Africa**
Planting Hoe - Sasakawa	9.00 €	6.35 €	3.57 €
Ridging Hoe	9.00 €	12.69 €	8.35 €
Weeding Hoe - Flat blade	9.00 €	13.96 €	5.47 €
Land Clearing Hoe - Curved blade	9.00 €	8.88 €	5.59 €
Average Cost of Each Tool	**9.00 €**	**10.52 €**	**5.72 €**
Number of Tools for Each Participant (Maximum)	**4.00 €**	**4.00 €**	**4.00 €**
Cost of Set of Tools/Participant	**36.00 €**	**42.06 €**	**22.89 €**
Average Cost to Produce N = 200 Sets of Improved Tools	**7,200.00 €**	**8,412.96 €**	**4,578.22 €**

7.5. Discussions and Conclusions

Malawi is not atypical with regards to the type of technologies that smallholder famers have access to. However, unlike most developed countries where agriculture is now heavily mechanized at a low cost, most farming in Malawi and developing countries relies on human power and specifically women, who are a major contributor of labour in agricultural and household tasks. There is also very little mechanization available, based on responses from the target groups, and the what is available is not accessible by smallholder farmers who typically rely on manual forms of labour. There is large mechanized equipment available to estate owners and those with large farmland as they can afford the initial capital costs to acquire and maintain such equipment.

Based on research conducted and corresponding literature review completed, it is therefore paramount to further explore a market-based, farmer-centered and engaged approach where the farmers actively make contributions towards the design, testing and use of the new and improved technologies and tools. As the NUI Galway 3D4AgDev research is based on a user-led innovation approach, the market assessment conducted was able to capture the differences in the approaches used to establish best practices for ensuring sustainable uptake and adoption of labour and energy saving technologies emerging from a farmer-led process.

Based on the findings above, there is clearly a market gap in Malawi that can be tapped into to better serve smallholder farmers and other involved in agriculture to transform how these labour intensive activities are carried out. Retailers and tool producers need to have better knowledge of their changing supply and demand sources to strengthen the markets for agricultural tools. NGOs and FOs are also lacking concrete data on the needs of their beneficiaries that results in services and products being handed out to farmers with no justification based on completed market research. This market report also highlights the gaps in the extension services that are entrusted to be well connected and aware of the market gaps smallholder farmers currently face in Malawi. It creates an opportunity for all value chain actors to try and focus on the needs of the customers and improve access for improved labour-saving tools for farmers.

Based on findings above, the researchers see the potential for a social enterprise that engages women farmers and their communities in the research and development of improved hand-held agricultural tools. Through the social enterprise approach, the farmers who are part of the process of developing tools are expected to have ownership and interested in marketing farmer co-designed innovations that other farmers can relate to. From the market survey carried out, the value chain supply actors have expressed interest in working with these social enterprise models to enhance the markets for hand-held agricultural tools, with the intention of further expanding to mechanized options.

The market study also highlights the lack of local manufacturing facilities, which is a result of lack of financial and human resources, both from the public and private sectors. Value chain actors in the market for quality and labour-savings tools experience several challenges when attempting to source tools locally due to a lack of resources to establish sustainable manufacturing facilities that can promote local production and use. The market assessment reflects the need to identify efficient and cost-effective ways to establish a local manufacturing facility that promotes the farmer-led and user-supported production of improved agricultural tools that will benefit Malawian smallholder farmers and strengthen the currently deficient market for these much-needed tools.

While there is strong evidence to support the efforts to migrate smallholder farmers to working with improved technologies that are preferably mechanized (Bao Huy, 2002; Doss, 1999, 2001; Olmstead & Rhode, 2014; Quisumbing & Pandolfelli, 2009; Watson, 2008), the reality among the 102 smallholder farmers interviews indicates a major disconnect between the financial capacity of smallholder farmers and their actual need for improved tools to boost their productivity as noted by (Bunderson et al., 2009b; Sims & Kienzle, 2017). Many of the farmers interviewed still felt that the hoe was the ideal tool for farming in Malawi as it is within most Malawian farmers' budget and reach (Sibande, Bailey, & Davidova, 2015). In addition, the farmers highlighted that the hoe is the most used hand held farming tools (Kienzle & Murray, 1998) and they indicated the need to improve the hoe and referred to the various customized hoes as "advanced" and "improved" hoes as stated by (Singh & Agarwal, 2009).

The busiest months for sales as indicated by retailers in between October and December when smallholder farmers prepare their land and get ready for planting in late November and early December (C.Rhoades, 1995), depending on when the rains begin this was also observed by (Wodon & Beegle, 2006). The highest sales month was indicated as October when land clearing and in some parts of Malawi, ridging activities take place. The highest tool indicated for these activities were the advanced hoe and improved ridging tools (Ashburner & Kienzle, 2013; IFAD/FAO/FARMESA; Kienzle & Murray, 1998; Snapp, Rohrbach, Simtowe, & Freeman, 2002).

As highlighted in earlier results section, the price of the hoe as of March 2016 was approximately the same price as it was when the initial markets and resource mapping activities were completed. This is despite the fact the local currency has dropped in its value (The World Bank, 2016) and other retail market prices have increased accordingly. Such increase lead to low agriculture productivity as reported by (Fuglie, 2008). Farming inputs have not had such a drastic increase in prices and has remained comparatively similar to what the prices were back in phase I period of the research, and this is in contradiction with what (Schiesari & Mockshell, 2017) reported.

To be able to successfully and sustainably disseminate these women-farmer-designed tools and agri processing technologies, the pricing of the tools will initially have to be on the lower end to increase the purchase probability once farmers are sensitized on the benefits of the tools as they will be promoted as labour/energy and time saving tools that are customized to activities and tailored to increase productivity and efficiency of work . As a result, considerations on how to strategically disseminate these farmer co-designed hand-held agri tools in an affordable and accessible way for smallholder farmers must be made, since women are regarded to have low access to resources (Siqwana-Ndulo, 2007). This must be accomplished in a cost-effective way to break even on production costs or have a little surplus. To attract users and suppliers of hand-held agri tools, products will be marketed at low price for a pre- defined period of time.

The results of the market assessment indicate that there is no shortage in the number and types of sellers of hand-held agricultural tools for smallholder farmers in Malawi. After careful observation of the physical locations of the retailers and local producers as well as through informal discussions with the retailers, the main obstacles to being able to provide quality and affordable labour-saving tools is the lack of funds and awareness (Siqwana-Ndulo, 2007) of improved labour-saving farming tools as most of the respondents are from low income households and mostly uneducated and illiterate (Ferreira, 2018). The best distribution channels will need to be within close proximity of the farmer's households. Farmers usually have to walk many hours to get to their destinations. By concentrating on locations that farmers can easily access, dissemination strategies can be put in place for sustainable distribution of these tools. This is of course with the understanding that mutual collaborative agreements can be made with the EPAs, NGOs and FOs to partner in the dissemination and training of new and improved farmer-designed agricultural tools for farming activities in Malawi.

Given the adequate amount of financial resources and technical support, distribution and sales of improved hand-held farming tools can be made more accessible by youth entrepreneurs interested in venturing into "more lucrative aspects" of agriculture than farming by becoming sellers of improved tools. In addition, for women smallholder farmers who expressed a strong desire to start a business with the time saved from using labour-saving tools and technologies (NUI Galway 3D4AgDev innovators' feedback), engagement in the design and uptake of tools and training on use of these tools would generate interest from these groups who want to start income generation activities to supplement their farming income and give them some extra financial security. As previously mentioned, this PhD research also aimed to also assess the effects of the research on the women innovator groups and their households. Specifically, the following chapter covers effects of participating in the research project, effects of being labelled an innovator, effects of participating in group design work and finally, effects of the tools on their incomes and overall productivity. The final chapter of this research presents the evidence from the baseline and endline survey as well as the impact assessments conducted to assess changes in the levels of empowerment and attitudes among the women innovator groups and their communities.

8. CHAPTER 8: MEASURING EFFECTS OF RESEARCH ON WOMEN FARMERS

8.1 Research Rationale

The overall thesis summarizes the detailed research activities conducted to harnesses user-driven innovation with 16 women smallholder innovator groups in Malawi to co-design, prototype and test labour-saving agri-tools tailored to women farmers and their farming systems. This chapter summarizes the research activities conducted to:

- *capture baseline data on the target groups at the beginning of the research,*
- *measure any differences in baseline and endline data on the target groups at the end of the tool design, production and testing stages,*
- *investigate the benefits and challenges observed by the women farmers during the use of the disseminated labor-saving tools (2018-2019 farming season).*

8.1.1 Strategy for Empowering Women Smallholders

The research program's empowerment strategy drew on elements of farmer participatory technology development, user-driven innovation and social enterprise development so that women innovator groups were enabled to design, develop, deploy and benefit from labour-saving tools tailored to their prioritized labour-saving needs. The programme used a survey-based index designed to measure the empowerment, agency, and inclusion of women in the agricultural sector, in a participatory manner (Alkire et al., 2013, Conroy and Sutherland, 2004, Biggs and Smith, 1998, Matsaert et al., 1997, Murray, 2015, Sraboni et al., 2014) . This research had an explicit focus on identification and fostering of rural women innovators, where the women innovators are both partners and beneficiaries, to improve the innovation development hence technology development as promoted by (Adekunle et al., 2012, Bellotti and Rochecouste, 2014).

8.1.2 Target Group Background Regarding Current Research

The primary target group are women smallholder farmers from Lilongwe and Kasungu districts in Central Malawi, specifically 187 women smallholder innovator groups that research worked with from 2013 to date. Through a questionnaire survey conducted during an innovator screening exercise, 186 women smallholder farmers were selected as *"best-bet"* innovators with the highest potential of conceptualizing agri innovations for labour-saving technologies. It was expected that as the women smallholder farmers are engaged through the problem identification phase before co-designing these concepts, the co-developed innovations would be tailored to their cropping systems.

8.2 Research Objectives

This chapter summarizes two main objectives;

- To summarize the observed effects of *(a) being selected as an innovator, (b) participating in group co-design process and testing and (c) using the labour-saving tools*. The research had a gender lens and utilized the project-based Women's Empowerment in Agriculture Index (WEAI) (Alkire et al., 2013) to capture baseline and endline data that could be compared to assess changed in levels of empowerment among the innovator groups arising from different components of this research work with women innovator groups.

- To conduct an impact assessment 1 year after women innovator ran additional research questions covered in this chapter included whether there were impacts on incomes, labour distribution and social lives of the innovator groups as a result of receiving the customized tool-kits that were distributed to them after mass production in October 2018 as briefly mentioned in chapter 6. This chapter includes a detailed review of the impact evaluation conducted in September 2019 to measure the effects of the tools on the lives of the women innovator groups who co-designed and tested the produced prototypes against existing tools and methods.

8.3.1 Selection as an Innovator "Innovator Effect"

The research hypothesis was that, through the selection of women farmers as innovators, the levels of empowerment for those selected to participate as women farmer innovators would increase as compared to those who were not selected. According to (Diederen et al., 2003, Peres et al., 2010), innovators are the first farmers in their market to use a certain innovation. This was one of the characteristics that were used in the scoring criteria. Another aspect is the one that (Murray, 2015) recognized; the ability of the farmers to serve in a community as role models, with the aptitude to deliver results and build trust. Innovative farmers influence other farmers through working to serve local problems in such a way that they may adopt a research concept, test and refine it in the field to find in-situ solutions that are passed on to others farmers so that they may do likewise, which in turn may influence other actors to extend the process (Bellotti and Rochecouste, 2014, Baliwada et al., 2017, Subrahmanya, 2010). In this study, innovators were chosen based on a criterion with respect to a set of characteristics which they possess that were classified as "innovative" and are also documented by other researchers (refer to chapter 2, page 32). This research aimed to assess the effects of being selected as a best bet innovator. The research also aimed to investigate the changes in levels of empowerment as a result of actually participating in the co-design of labour saving agricultural tools.

This study aimed to assess the benefits of this participation on their mindsets and way of life after the research was completed.

8.3.2 Group Effect

Research has shown evidence of working in groups and the effects of a person's empowerment. Individual versus group work indicates higher benefits when working with a group (Subrahmanya, 2010, Loevinsohn et al., 1992, Loevinsohn et al., 1994).This chapter summarizes the discussions with the target groups to investigate the effects of involving women farmer groups in the participatory research and innovation development with the hope that the technology development may lead to women empowerment (Alkire et al., 2013, Gebremedhin et al., 2015).

8.3.3 Experimenter Effect

To test out the effects of Participatory Technology Development (PTD), the research engaged the farmers in a participatory user-led design and development process to conceptualize labour-saving ideas for agri tools. This is a client-driven process that requires decentralized technology development, devolves to farmers the major responsibility for adaptive testing, and requires institutions and individuals to become accountable for the relevance and quality of technology on offer (Ashby and Sperling, 1995, Bao Huy, 2002, Conroy and Sutherland, 2004, Douthwaite et al., 2002, Matsaert et al., 1997). User-led and user-centered innovation tool design sessions were conducted with women smallholder innovator groups to develop labour-saving and productivity-enhancing tool designs (Humphreys et al., 2005, Ornetzeder and Rohracher, 2006).

During each participatory discussion session, the women smallholder farmers brought the existing tools they currently used and took measurements of tool dimensions for existing tools used for identified labor-intensive cultivation and post-harvest tasks. Each innovator group was then engaged to analyze the measured tool and rate it for effectiveness. Those tools that were ranked as ineffective were placed at the center of each focus group discussion where the women were asked to recommend various ways of improvements or refinements to the tool. Each women's innovator group identified and conceptualized 2 to 4 designs per group for the prioritized cultivation and post-harvest tasks. These co-designs were uniquely coded and are fully traceable to the women farmers' innovator groups.

8.3.4 Tools Effect

Overall, after the research proved that women are capable of innovating and can design agricultural tools that are labour-saving and tailored to their cropping needs. The ability of farmers to come up with innovations has been studied by several researchers such as (Aas and Breunig, 2017, Holmén et al., 2007, Röling et al., 2004, Subrahmanya, 2010, Ton et al., 2011), and has been demonstrated in this research as summarized in chapters 4 to 6. However, an assessment of the effects of this tool development and testing process on the women's' potential has not been conducted. The research meticulously recorded the women's time given to this research activities through focus group discussions (FGDs), field tests, feedback sessions, provision of farms for testing, and provision of existing tools for testing. Once the research was completed, each of the 187 best-bet innovators received the labour-saving set of tools that they co-designed and successfully tested. The research aimed to also investigate the overall benefit of the tools for the women farmers and their households.

8.3 Research Methodology

The research applied two methodologies that are well detailed in this chapter:

- *Measurement of changes in women's level of empowerment,* using the WEAI tools to compare baseline and endline results collected from the women innovators and a control group, based on the above parameters.

- *An independent impact evaluation conducted in September 2019 by GIZ Malawi* to assess the impacts of the improved hand-held tools distributed to the innovator groups in October 2018. The funder contracted an independent consultant who, with support from the 3d4agdev PhD researcher, developed the survey tools, recruited enumerators and conducted the impact evaluation. The contribution of the PhD researcher was to assist in identifying the sites to be assessed and introductions to the innovator groups. This study was carried out 1 year after the improved sets of toolkits were distributed to the women innovators as a compensation for time given to the research for the tool co-design and production process. The study aimed to capture any significant changes in the lives of the women innovator groups as a result of participating in the research and using the improved handheld tools in the 2018-2019 planting season. This study focused on quantitative and quantitative aspects to assess the most significant change observed in the women farmers' lives since they; *1) were selected as innovators, 2) took part in the tool-co-design sessions, 3) took part in the tool testing sessions* and *4)used the tools over the last planting season*.

8.3.1 Measuring Empowerment: Women's Empowerment in Agriculture Index

The index was developed by IFPRI and was used to identify relevant empowerment indicators that would be measured in this study. The index intends to measure several factors that are tailored to the woman farmer and empowerment domains relevant to the women farmer (Alkire et al., 2013, Sraboni et al., 2014). The women innovator groups completed baseline and endline questionnaires and ranked their input in decision making regarding the following:

a) *General household decisions regarding income and expenditure*
b) *Agricultural production i.e. crops to grow and tools and inputs to buy,*
c) *When to take or who should take crops to market*
d) *Purchase, sale, or transfer of land and assets*

The research paid special attention to assess levels of empowerment of the women smallholder innovators, by monitoring and measuring how the women themselves gain greater control over their livelihoods. For example, WEAI indicators were applied to measure whether women when engaged indicate that the tools reduce their workload, and can express how they have now used the time saved from use of the new hand-held agri tools and if as a result, these women perceive that they have greater control in decision making around their manual work (Alkire et al., 2013, Barrett and Browne, 1994, de Brauw et al., 2008). Respondents also indicated their leadership roles in civic, social or community groups and their level of comfort with public speaking. This enabled the assessment of the woman farmer's leadership potential from the baseline to endline period and assess whether the changes were as a result of participating in this research, all other factors considered.

The research borrowed elements from the project-based modules and conducted a baseline Q-study of women innovators engaged in the research. The research had aimed to have a larger study using the empowerment index but due to resource limitations, this precluded a large-scale application of the WEAI in Phase I and as a result, the research opted for a scaled-down version of the WEAI modules and developed 14 project-based questions that were used as part of a baseline study of 173 women innovators. Refer to the appendix section for a sample of the questionnaire used.

Follow on Refresher Training on WEAI for project research team

The research team consulted with IFPRI WEAI trainers on women's empowerment assessment who provided additional expertise and understanding to the researcher conducting the study of empowerment effects. Once the research activities had been completed, the same questions were applied to gain a measure of any empowerment of the women innovator groups that could be traced back to this research.

8.3.2 GIZ-Funded Independent Impact Assessment Study

The second methodology applied to assess the impacts of the research on the women innovator groups was an impact evaluation study that was independently carried out in September 2019 by a consultant contracted by the Malawi Green Innovations for Agriculture Sector (GIAE) programme who funded the field-testing, production and dissemination of improved handheld tools to women innovator groups that was completed by October 2018. The aim of this study was to assess the impacts of the disseminated labour-saving tools as observed by the women farmers innovator groups who received the tools.

The women farmers selected as "best-bet" innovators who participated in the co-design of agricultural tools received the tool sets made up of 6 customized hand-held labour-saving agri-tools that were distributed by the research program on 1-2nd Oct 2018 to each of 187 smallholder women farmer innovators (i.e. 1122 tools). The research wished to determine whether the expected labour savings were observed by the women farmers in the 2018-2019 planting season and in the 2019 irrigation season (April to September). GIAE recruited 10 enumerators, who under the supervision of the GIZ consultant evaluated the impacts of the tools on the women farmers' household income (including ability to pay for tools), livelihoods, health, empowerment and adoption of labour-saving and climate-smart agriculture (CSA) practices.

The impact assessment targeted the 187 women smallholder farmers who received the tool sets of labour saving hand-held agricultural tools in Kabudula and Nkhamenya areas of Lilongwe and Kasungu North Districts respectively. Due to the strict timeline and funding available for the study, 121 farmers who received the tools last year were interviewed for the study. In addition, evaluation comparison was conducted with a control cohort of women smallholders lacking access to labour-saving tools. This control group of women farmers are those who never participated in the 3D4AgDev user-led innovation research work but who reside in the same areas as the women innovator groups that 3D4AgDev worked with. For the control cohort, 161 women smallholder farmers were interviewed for the study. In addition, 12 Focus Group Discussions (FDG) were conducted with the spouses of the women innovators and control cohort women farmers. Extension staff who have supported the women farmers over the past planting season were also interviewed to get their feedback on the tools and the whole research approach.

8.3.3 Data Collection Techniques

To capture data on actual benefits and challenges observed by the users of the distributed GIZ GIAE-funded labour-saving agricultural tools and the control cohort of women, the research applied a mixed qualitative and quantitative approach using the following tools:

- In-depth key informant interviews and FGD guides for collecting qualitative data
- Structured questionnaires for collecting quantitative data

- Focus group discussions with spouses of women smallholder farmers, randomly sampled from both research sites to capture their experience and perceptions regarding the tools distributed to their households through their wives.
- Key informant interviews with extension workers and NGOs supporting the innovator groups in the past year who witnessed the innovator groups using the disseminated tools.

Table 8-1 : Sample Size summary table

Women Smallholder Farmers Innovators	121
Control Cohort	161
NGOs And Government Extension Staff	12
Husbands/Partners/Spouses (FGDs)	12 (Avg.10 Participants)
Total	299

Enumerators were trained on data collection tools and a pretesting exercise was conducted for a day before the actual field work to ensure that the survey tools are easily understood by all enumerators. After addressing corrections and suggestions from the pretesting, the tools and team was deployed for data collection for 8 days in September 2019.

For both methodologies, Computer Aided Personal Interview (CAPI) open source platform; Kobo Toolbox[2] was used, as such, no data entry was required. The recorded KII was transcribed and analyzed in NVIVO software. The data collected was then analyzed using Statistical Package for Social Scientist (SPSS) and Microsoft Excel where applicable to develop descriptive statistics. The outcomes of the studies are presented in the results section.

8.4 Results

8.4.1 WEAI Comparison of Baseline and Endline Data Analysis

Baseline and endline data that was obtained from interviews that were done with the aid of a questionnaire were analyzed in SPSS where cross tabulations assisted in comparing data from the two regarding decision making in a number of activities. The results were summarized in form of figures (graphs) and tables with the aid of Microsoft excel package.

Decisions Making: Agricultural Production

Women smallholder farmers were individually asked to what extent they feel that they can make their own personal decisions regarding agricultural production if they wanted to. Respondents were asked to indicate their responses ranking them from lowest to highest 1-5). Response options were: *1 - None, 2-Some, 3-Both Partners decide, 4-Most, 5-All.*

[2] Kobo toolbox is a free/open source tool for mobile data collection. It allows field data collection using mobile devices

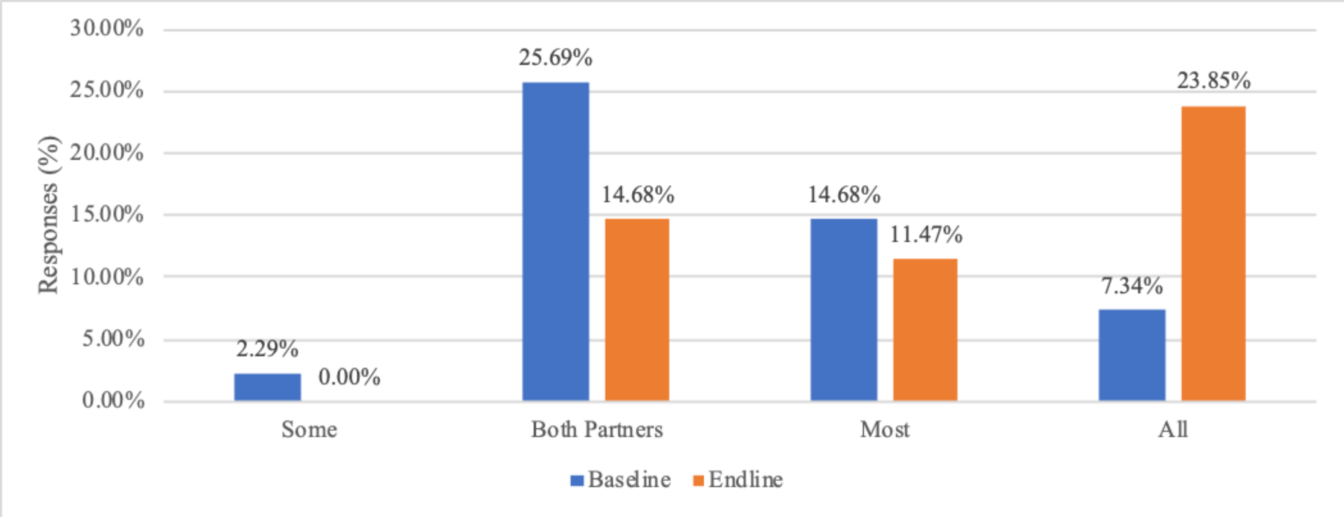


Figure 8-1: Extent of Decision Making Regarding Agricultural Production

Results from the baseline shows that a large percentage of the women didn't feel they can be able to make decisions regarding agriculture production on their own. This is so as indicated by a large percentage of those who said they required both spouses (25.69 per cent) to make such decisions. During the endline assessment, a large percentage (23.85 per cent) of them responded that they could be in a position to make almost all decisions regarding agriculture production.

<u>*Decision Making: Purchase Tools and Inputs*</u>

Women smallholder farmers were also asked to what extent they feel that they can make their own personal decisions regarding the purchase of tools and inputs if they wanted to. Respondents were asked to indicate their responses ranking them from lowest to highest 1-5). Response options were: *1 - None, 2- Some, 3-Both Partners decide, 4-Most, 5-All.*

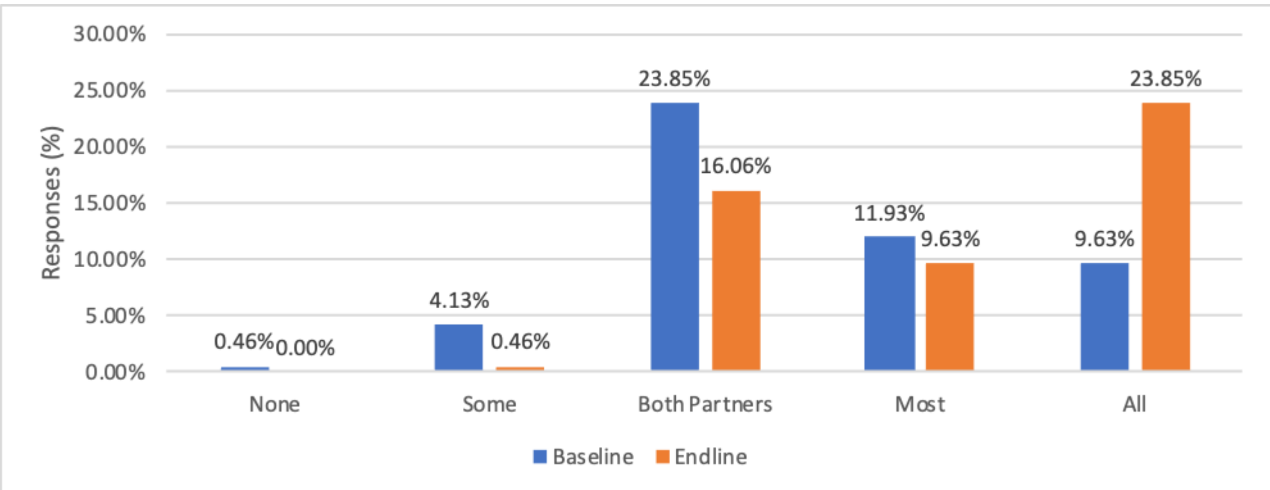


Figure 8-2: Extent of Decision Making Regarding the Purchase of Tools & Inputs

With respect to the results shown in the figures above, a large percentage of the women at first didn't feel they can't make decisions regarding tool purchase on their own. This is so as indicated by a large percentage of those who said they required both parents (23.85 per cent, baseline results) to make such decisions but it was later observed that a large percentage (23.85 per cent, endline results) of them responded that they could be in a position to make almost all decisions regarding the same.

At the start of the research, 8 per cent of surveyed women farmers indicated that they felt they only had decision making abilities for "*some"* of the decisions made regarding the purchase of tools and inputs. The endline survey results collected and analyzed at the end of the research indicate that only an estimated 1 per cent of the total respondents now fall in this category. Although 1 per cent of the responses from the baseline survey indicated that they felt they had no decision-making abilities regarding the purchase of tools and inputs, no one in the endline survey indicated the same. Based on the baseline data analysis results, only 19 per cent of the women smallholder farmers had indicated that they felt they had decision making inputs in all discussions regarding the purchase of tools and inputs. However, endline results indicate that almost half of the of women smallholder now feel that they can make all the decisions regarding the purchase of tools and inputs (estimated 48 per cent).

Decision Making: What Crops to Grow

Women smallholder farmers were individually asked to what extent they feel that they can make their own personal decisions regarding what crops to grow if they wanted to. Respondents were asked to indicate their responses ranking them from lowest to highest 1-5). Response options were: *1 - None, 2-Some, 3-Both Partners decide, 4-Most, 5-All.*

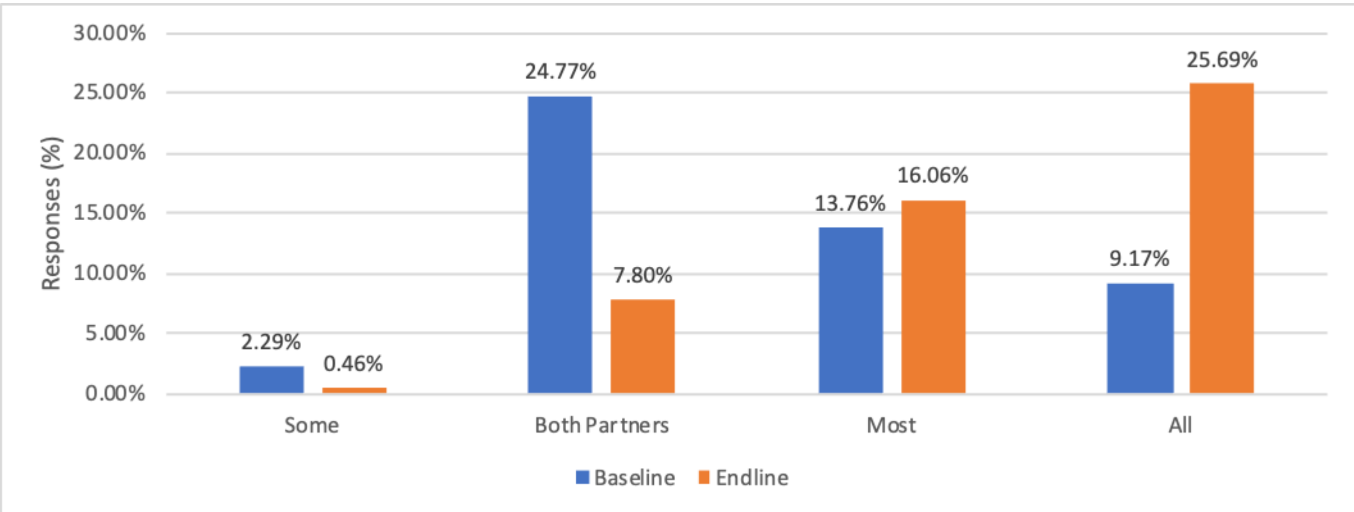


Figure 8-3: Extent of Decision Making Regarding What Crops to Grow

Regarding decision making in the types of crops to be grown, results above indicated a large percentage of the women who at first didn't feel they can't make decisions on their own regarding the type of crops they can grow. This is so as indicated by a large percentage of respondents who said they required both parents (24.77 per cent, baseline results) to make such decisions. It was later noted that a large percentage (25.69 per cent, endline results) of the respondents responded that they could be in a position to make almost all decisions by themselves regarding the type of crops they should grow.

Baseline survey conducted before the start of the labour-saving technology development research indicated that 50 per cent of the respondents decided on what crops to grow with their partner/spouse. This figure significantly dropped to 16 per cent based on the endline survey results. The number of respondents who indicated that they feel they can now make *all* decisions regarding what crops to grow increased significantly. There was a sharp increase from 18 per cent before the research to 51 per cent at the end of the research. Although minimal, the number of respondents who felt they could only make *some* of the decisions also dropped from 5 per cent to 1 per cent in the endline survey.

Decision Making: When and Who to Market Farm Produce

The women farmers gave their responses regarding the extent to which they felt they could make their own personal decisions regarding when to take or who should take crops to market if they wanted to. Respondents were asked to respond to questionnaire surveys and give their responses based on a scale ranked from lowest to highest: *1 - None, 2- Some, 3-Both Partners decide, 4-Most, 5-All.* The figure below indicates the comparison between the results of the baseline and endline surveys.

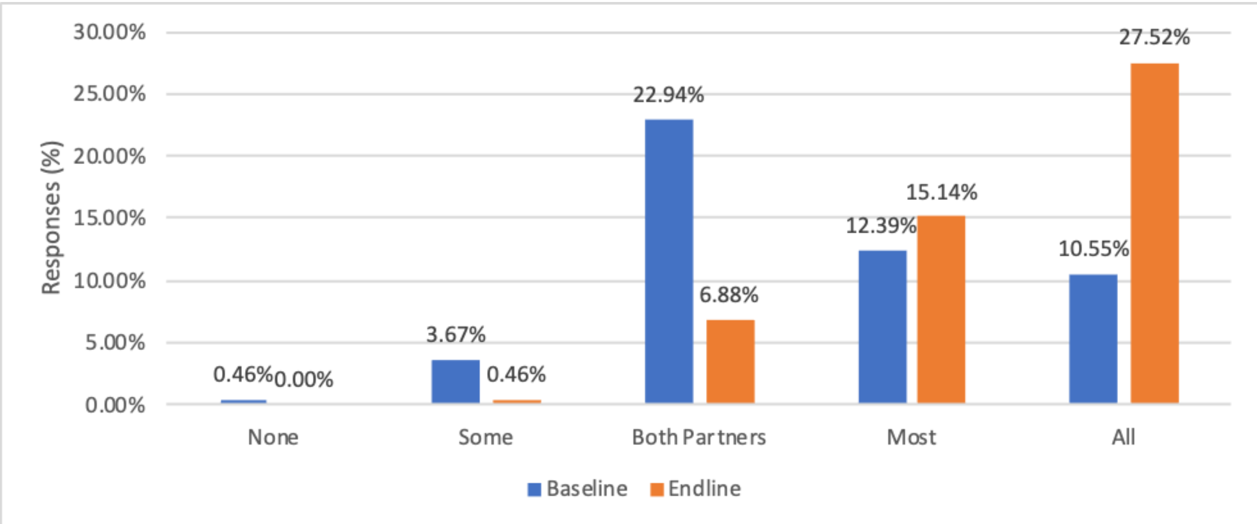


Figure 8-4: Extent of Decision Making: Taking Crops to the Market.

It was observed in this study that a large percentage of the farmers could not make decisions regarding who to take crops to the market as indicated in the results above. The results show a large percentage of the women who at first didn't feel they can make decisions on their own regarding who to take crops for sale as indicated by a large percentage of respondents who said they required both parents (23 per cent, baseline results) to make such decisions. But it was later noted that a large percentage (28 per cent, endline results) of the respondents responded that they could be in a position to make almost all decisions by themselves.

Before the start of the research, approximately 7 per cent of the surveyed women smallholder farmers indicated that they felt they only had decision making abilities for "*some"* of the decisions made regarding the when and who to market crops. The endline survey results collected and analyzed at the end of the research indicate that only an estimated 1 per cent of the total respondents now fall in this category. There was also a decrease in the representation of respondents who felt they needed to consult their spouses before a decision was jointly made. The baseline results showed 46 per cent of the respondents decided jointly with their spouses compared to only 14 per cent from the endline survey. There was a slight increase in those who felt they could make most of the decisions. From the baseline survey, 25 per cent felt they were in this category compared to a higher estimated 30 per cent from the endline survey. Based on the baseline data analysis results, only an estimated 21 per cent of the women farmers had indicated that they felt they had decision making abilities in all discussions regarding when and who to market crops. On the contrary, the number of respondents increased to 55 per cent based on the research endline results.

<u>*General Decision Making in the Household*</u>

The baseline and endline surveys captured responses from women farmers regarding the extent to which they felt they could participate in general decision-making in their household. Respondents indicated their answer based on a ranked scale from lowest to highest. *1 = not at all, 2 = small extent, 3 = medium extent, 4 = to a high extent.*

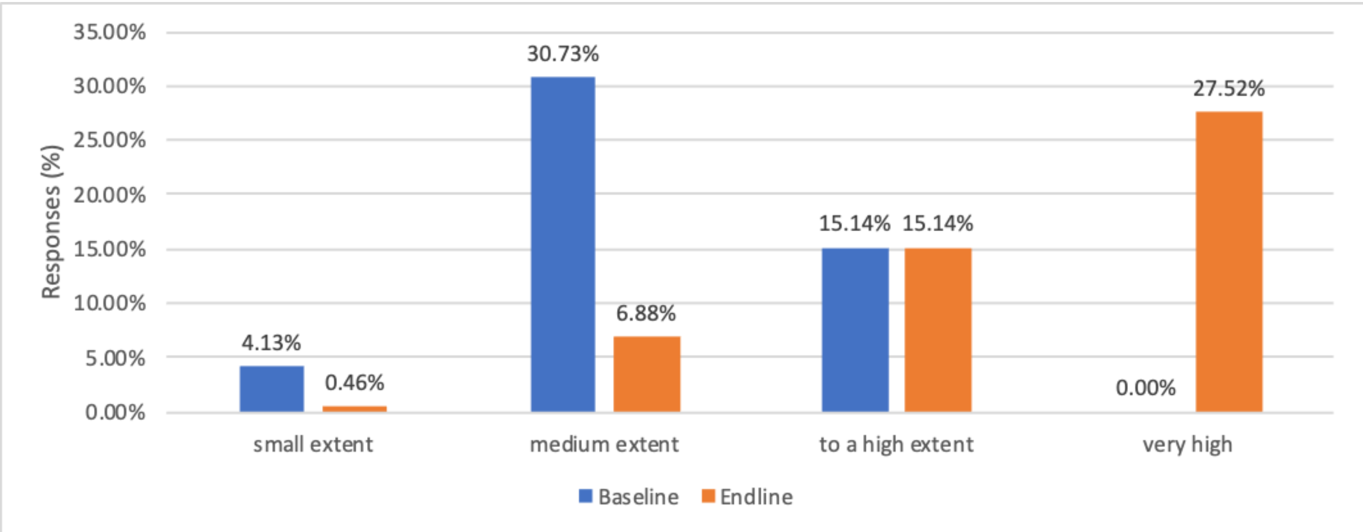


Figure 8-5: Women Smallholder Farmers' General Household Decision making.

This study indicated that at first, a large percentage of the female farmers could not make decisions regarding when and who to take crops to the market as shown in the results. However, after the endline survey, a large percentage (31 per cent) of the women who at first didn't feel they can make decisions on their own regarding when and who to take crops for sale are now able to. It was later noted that a large percentage (28 per cent, endline results) of the respondents responded that they could be in a position to make almost all such decisions by themselves.

Baseline results indicated that 61 per cent of the respondents felt they could only participate in general household decision making to a *"medium extent"*. This is a sharp contrast to the endline results show only 34 per cent who responded the same. The respondents from the baseline survey indicated that 30 per cent were of the opinion that they could participate in all general household decisions to a "*high extent*". The results of the endline survey indicate that the number of respondents who indicated the same response has doubled. There are now 65 per cent of the respondents the same way.

Women Smallholder Farmers' Level of Comfort with Public Speaking

The women farmers were also asked to rate their level of comfort regarding speaking in public about issues in their community. They were asked to select one of the responses from the scale below: *1 = not at all comfortable, 2 = with a little difficulty, 3= fairly comfortable, 4 =very comfortable, 99= DNR*

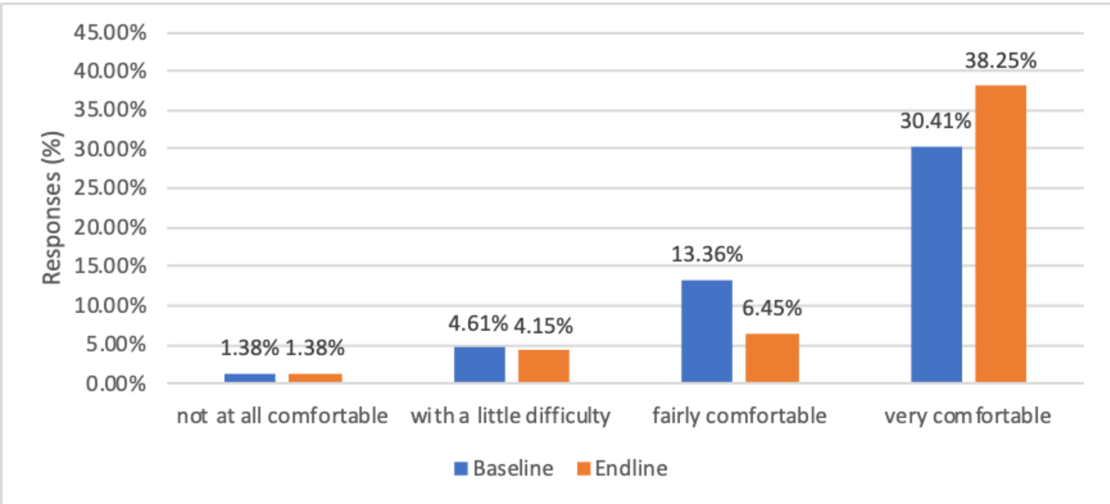


Figure 8-6: Level of Comfort with Public Speaking About Community Issues

There was an increase in the percentage of respondents with comfortability in speaking publicly about community issues after than before the baseline study. This was observed from increase in the respondents (38 per cent to 39 per cent) who showed high comfortability in doing so.

Baseline results indicated that 61 per cent of the women farmers felt very comfortable with public speaking while the endline results show 76 per cent who indicated the same. Interestingly, the same number of respondents indicated that they were "not at all comfortable" in the baseline and endline survey. There was a slight improvement among the respondents who indicated that they can speak publicly "with a little difficulty" The number respondents decreased from 10 per cent from the baseline survey to 8 per cent from the endline survey. This may be as a result of more women feeling comfortable with public speaking as a result of them practicing during the research focus group discussions.

Decision Making: Land & Assets

Women farmers were asked to rate the extent to which they can you make decisions regarding the purchase, sale, or transfer of land and assets? Responses were ranked as: *1 = not at all, 2 = small extent, 3 = medium extent, 4 = to a high extent.*

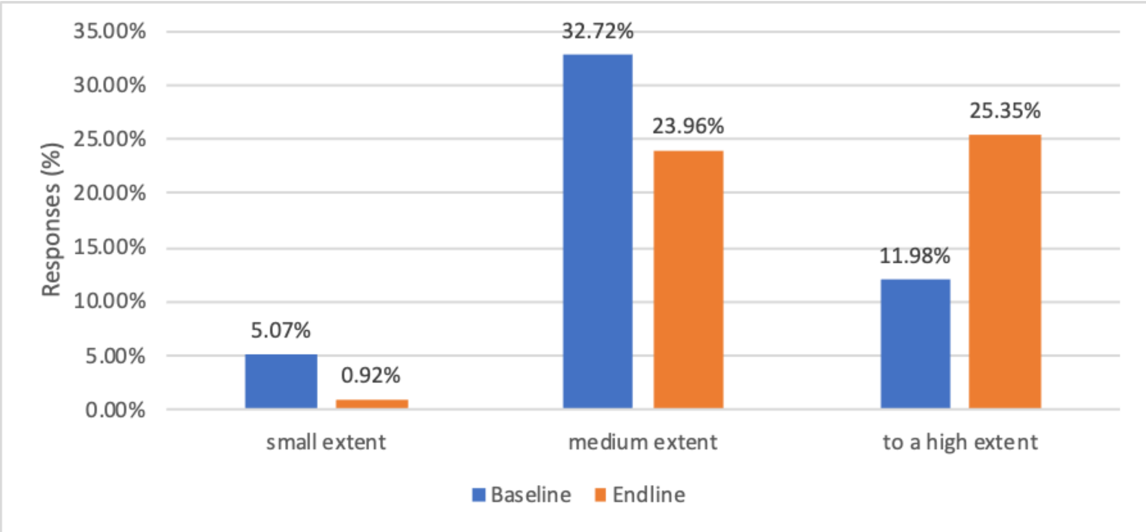


Figure 8-7: Decision-Making Regarding Purchase, Sale, Or Transfer of Land and Assets

These results indicate that the extent to which women farmers could be involved in decision making regarding purchase or sale of land was higher at the endline stage of the study as at the baseline. There was a very low percentage of farmers who responded to have high extent to in making such decisions in the endline (25per cent) than the baseline stage (12 per cent).

According to the results presented for the baseline and endline survey, the number of respondents who indicated that their extent of decision-making regarding land and assets was "high" went from approximately 24 per cent from the baseline period to about 50 per cent based on the endline results. While an estimated 11 per cent of the respondents indicated that they only make decisions to a small extent, the endline results show only 2 per cent who feel the same. There was also a decrease in the number of respondents who indicated that they only make decisions to a "medium" extent. The results altered from 65 per cent at baseline to 48 per cent at the endline.

Decision Making: Use of Household Income

The surveyed women innovator groups were also asked to indicate the level of input they had in decisions made about the use of income generated from farming and other income generating activities:

Answers were ranked as: 1= *no input, 2 = input into very few, 3 = input into some, 4= input into all, 99=did not respond.*

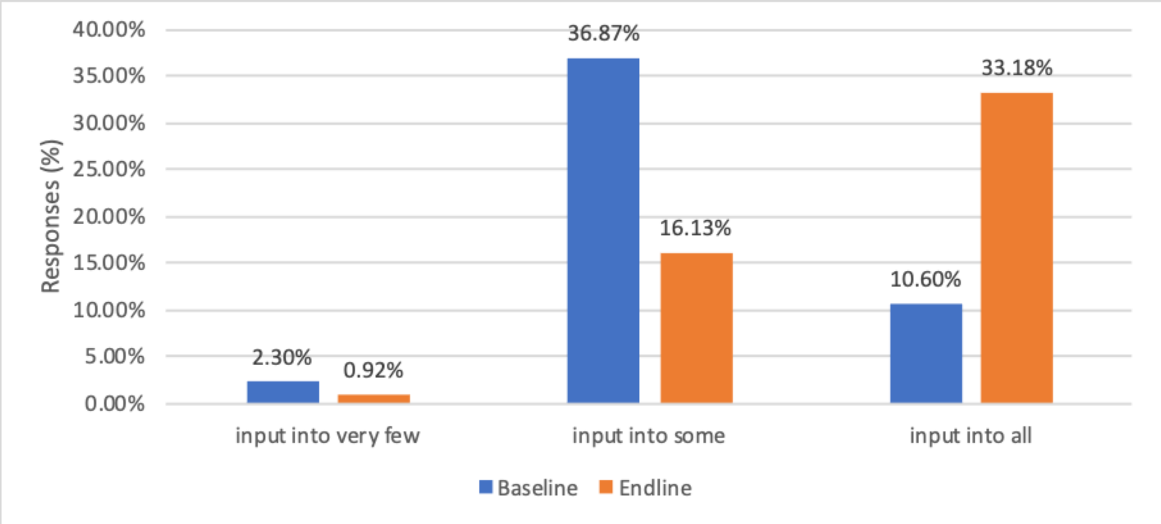


Figure 8-8: Level of Input in Decisions Regarding Use of Generated Household Income

The above results indicate that the extent to which women farmers could be involved in decision making regarding the use of household income was higher at the endline stage of the study as compared to the baseline. There was a high percentage of farmers who responded to have high level input in making such decisions in the endline (33 per cent) than the baseline stage (11 per cent). An estimated 66 per cent of the respondents from the endline indicated that they now have input into all the decisions made regarding use household income generated from farming and other activities. This is a significant increase from the results of the baseline where only 21 per cent of the respondents indicated the same response. Although minimal, the respondents who indicated that they had input into very few of these decisions decreased from 5 per cent based on baseline results to 2 per cent based on endline results.

<u>Decision Making Regarding Use of Personal Wages or Salary</u>

Women smallholder farmers indicated their responses regarding to what extent they felt they could make their own personal decisions regarding their wages or salary employment. Responses were indicated as: *1 - None, 2- Some, 3-Both Partners decide, 4-Most, 5-All, 99=did not respond.*

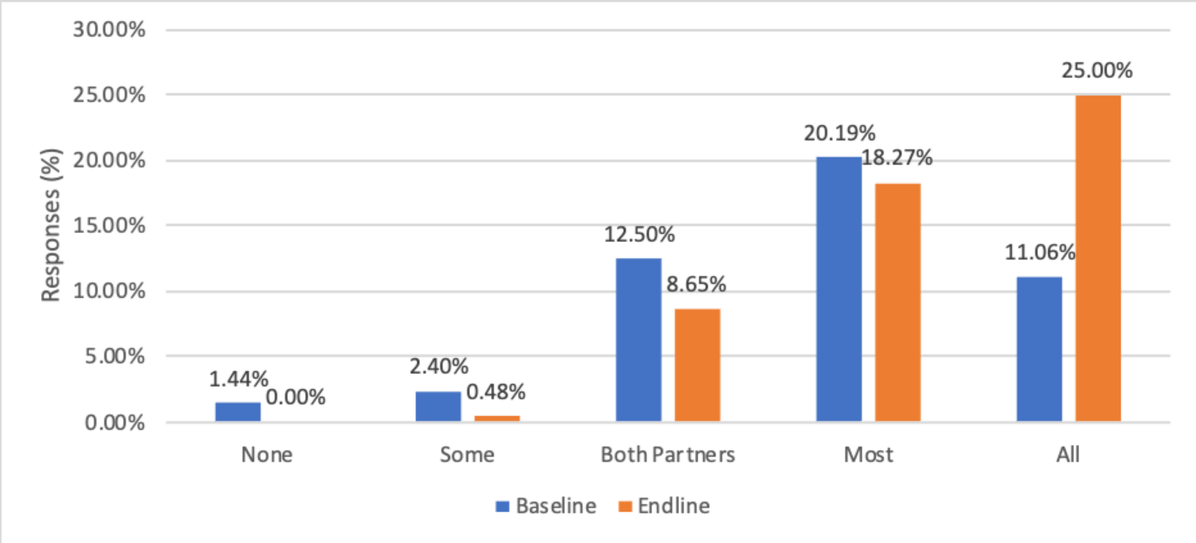


Figure 8-9: Decision Making Regarding Their Personal Wages or Salary Employment

Results indicate that the extent to which women farmers could be involved in decision making regarding the use of household income was higher at the endline stage of the study as compared to the baseline. There was a high percentage of farmers who responded to have high level input in making such decisions in the endline (25 per cent) than the baseline stage (12 per cent).

Baseline results indicated 21 per cent of the respondents felt they can make all the decisions regarding the use of their personal wages or salary employment were in this category compared to 48 per cent of the women farmer respondents who indicated that same in the endline survey. While the baseline results also showed that 3 per cent of the women farmers felt they had no input into the decisions made about their own personal wages or salaries, the endline results did not indicate this for any of the respondents. The respondents who indicated that they felt they could only make some of the decisions decreased from 5 per cent to 1 per cent in the endline results.

<u>*Decision Making: Household Expenditures*</u>

The research wanted to investigate to what extent women farmers felt they could make their own personal decisions regarding major and minor household expenditures. Respondents were asked to choose from a range of responses: *1 - None, 2- Some, 3-Both Partners decide, 4-Most, 5-All, 99=did not respond.*

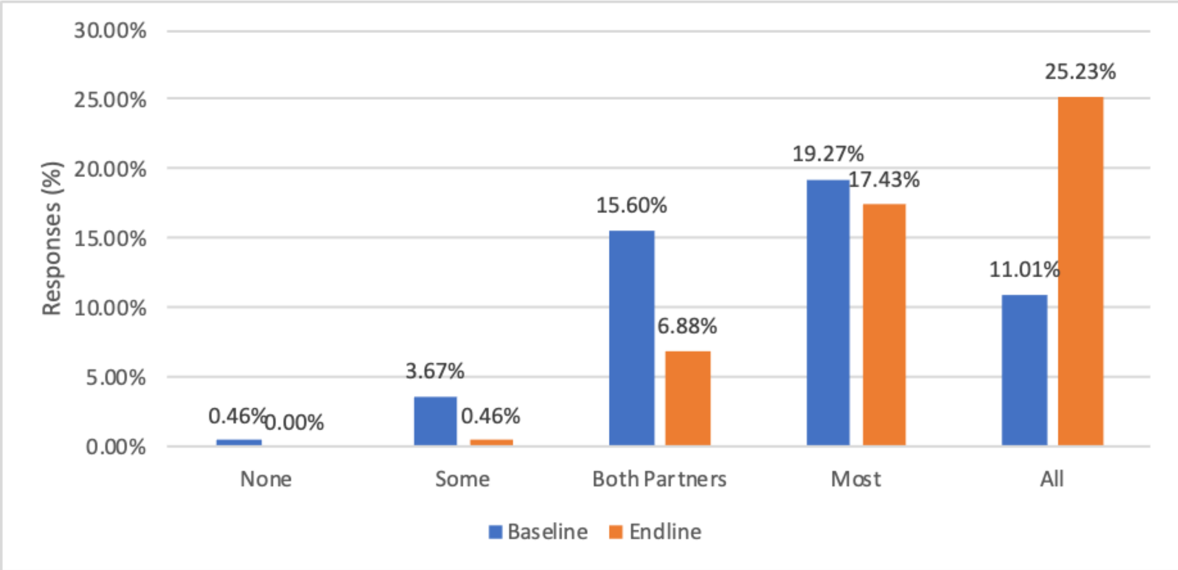


Figure 8-10: Decision Making Regarding Major and Minor Household Expenditures

Results of this analysis indicated that women were highly involved in contributing to the decisions regarding major and minor household expenditure after the endline of the study than the baseline period. Only 11 per cent of the respondents in the baseline were participating in deciding almost all issues regarding major household expenditure but the proportion (per cent) increased to about 25 per cent at the endline stage of the project.

the baseline results indicated that 1 per cent of the women farmers did not have any input in decisions made regarding major and minor household expenditures. The results from the follow up endline survey indicate that no farmers indicated this response. In addition, 50 per cent of the women farmers indicated that at the time of the survey, they had all the decision-making abilities regarding these household expenses. This is a great improvement from the baseline period where only 22 per cent of the women responded the same.

Decision Making: Access to Credit

The research also aimed to capture any changes in the respondents' decision-making ability regarding access to credit. They were asked to indicate how much input they felt they have on decisions regarding access to credit. Responses were ranked as: *1 = no input, 2 = input into very few, 3 = input into some, 4= input into all, 99=did not respond.*

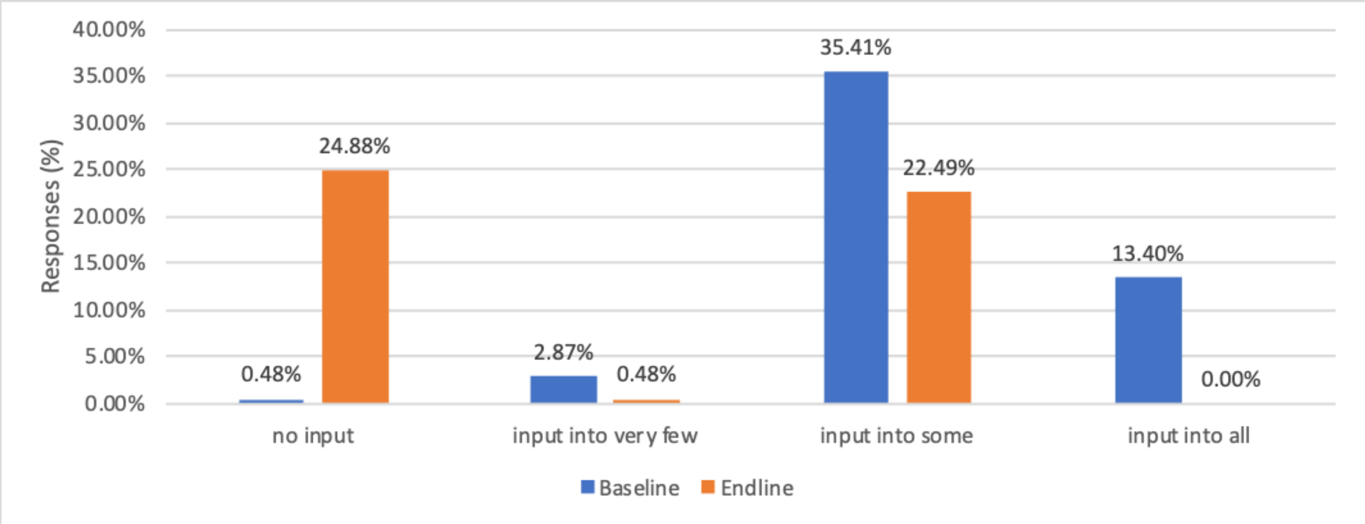


Figure 8-11: Decisions Regarding Access to Credit

Results on decisions to access credit has shown to be lower at the endline of the project than the baseline. A significant (25 per cent) proportion of respondents in the endline period of the study responded not to be involved in decisions regarding accessing loans as compared to the baseline results.

While 68 per cent of the respondents in the baseline period indicated that they have input into some of the decisions made regarding access to credit, the endline period indicates a sharp decrease to 43 per cent. Baseline results indicated that 26 per cent of respondents felt they have input into all decisions regarding access to credit. However, endline results indicate that not a single woman farmer has input into these kinds of decisions now. In addition, while baseline results indicate that only 1 per cent had no input in decision making on credit access, endline results indicate that 48 per cent of them now indicate no input into decision making on access to credit.

8.4.2 Findings from GIZ Impact Assessment Study on 3D4AGDev Women

This section presents the demographic information on the survey participants who were interviewed. As mentioned in the methodology section of this report, 8.3.2, the sampled farmers were based on participation in the program and those that have heard and reside in the same area as the beneficiary farmers.

Table 8-2 :Farmers' survey: general characteristics of the population

	Beneficiary women farmer households		**Control Cohort women farmer households**	
Characteristic	Respondents	Percent	Number of respondents	Percent
Sex				
Female	121	100%	161	100%
Marital status				
Married	106	87.6%	130	81%
Single	2	1%	2	1%
Divorced	6	5%	13	8%
Widow	7	6%	16	10%
Site				
Kabudula	57	47%	75	47%
Nkhamenya	64	53%	86	53%
Innovation adoption assets				
Ownership of Phone				
Yes	79	65%	61	38%
No	65	35%	100	62%
Radio				
Yes	49	40%	38	24%
No	72	60%	123	76%
House wall material and roofing material				
Burnt bricks and Iron sheets	57	47%	33	20%
Burnt brick and grass thatched	29	24%	60	37%
Mud and iron sheets	1	<1%	0	0
Mud & Grass thatched	5	4%	12	7%
Unburnt bricks and Iron sheets	3	2%	2	1%
Unburnt bricks and Grass thatched	26	21%	52	32%

Main Livelihood Sources

The main livelihood source in the 2 sites is farming at 93 per cent and 82 per cent for beneficiary and control cohort households respectively followed by small businesses and piece works for both groups.

Sources of Transport

The main mode of transport is On-foot for the control groups (60 per cent) and bicycle for the beneficiary group (51 per cent).

Access to land and productivity Estimates

The land holding size is 3.43 acres for the beneficiary farmers and 2.37 for the control group farmers. Below is the land holdings distribution between the groups.

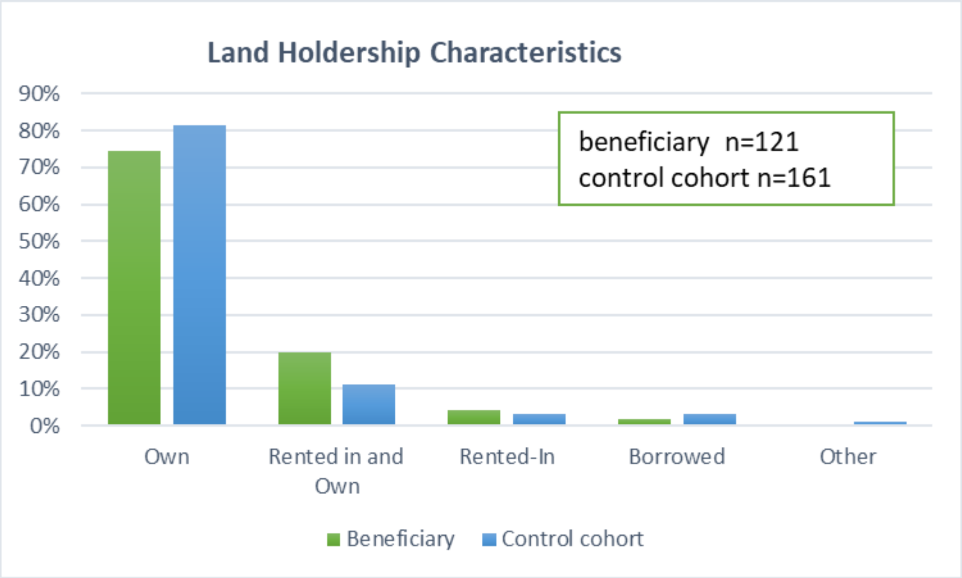


Figure 8-12: Land holdings characteristics of the 2 sampled groups

For most of the farmers, the yield has been decreasing in the past 3 years by between 10-25 per cent (beneficiaries 55 per cent and control group 70 per cent) however, 20 per cent of the beneficiaries against 7 per cent of the control group indicated that their yield has been increasing in the past 3 years. Though the increase in yield might be due to other factors too, the beneficiary women farmers indicated that having saved some time off their fields allowed them to do many other things. They mentioned that they could apply manure, cultivate larger pieces of land, find other sources of income to boost their agriculture as all these have direct positive impact on increasing their farm yields. More farmers tend to use both manure and fertilizer (50 per cent beneficiaries and 37 per cent control group), Fertilizer only for 34 per cent of both groups, Manure only (13 per cent beneficiaries and 17 per cent of the control group. Other farmers also did not apply anything to their soil (4 per cent of the beneficiaries and 11 per cent of the control group).

Beneficiary User Farming Experience

Beneficiary women farmers were asked to explain their experience using the customized tools over the previous cropping season and in their current irrigation plots farming. The tools changed the farmers experience completely in the previous season. The farmers appreciate the set of new tools given to them as they had enough tools for different agricultural tasks in the household. They indicated that they looked forward to farming and the tools brought excitement and they felt empowered to have co-designed them. They managed to farm larger areas and the tools improved the distribution of labour in the family as improved access to tools meant more family members joined the labour force and reduced workload because the tools were new and exciting to use and more family members were looking forward to trying them.

The customized handles meant that the tools were well adapted to their needs, the handle height was perfect and did not need too much bending. These ergonomic improvements improved their health and well-being as the farmers experienced little or no backaches the past season which has not been the case using their existing tools**.**

"The last season I was healthy and energetic throughout the farming year which hasn't been the case with the previous years'"

Anonymous Woman Smallholder Farmer, September 2019

"We are having more yields, without back pains from bending".

Anonymous Woman Smallholder Farmer, September 2019

Quotes from Women Farmer Innovators During Impact Evaluation Interviews

The control cohort had also borrowed and used the tools and their feedback was not different from the beneficiary's experience with the tools. The control groups also indicated that the tools were light, sharper and made them save time and energy in the field.

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Figure 8-13: Grace Chipeta and her husband with tools assessed during impact survey

<u>Time & Energy Savings and Household Labour Distribution</u>

Time and energy savings on different agricultural tasks using the improved tools enabled the women farmers an opportunity to find time to rest which they were constantly lacking. It also created more enough time to take care of their families and time to do other income generating activities such as small-scale businesses and irrigation farming. The improved tools enabled them to them improve their household labour division for on-farm and other tasks. Initially the expectation would be that the new tools would reduce labour (in terms on the number of people working in the field). However, a large percentage (84 per cent) of the farmers reported an increased number of people working in the field due to improved access to customized agricultural tools which was lacking before. Such improved tool access enabled the household to access and share the labour that was idle before. This increased the number of people working in the field within the household and significantly reduced workload and time spent in the field for the women farmers which in turn gave the women farmers more leisure time and more time to rest and take care of their families. The women indicated that they use the free time saved from the use of the new tools to do business, take care of their families and to rest. They women did not initially have time to rest with their days as after farm work, they had a lot of household chores to do which left them no time to rest.

<u>Quality of Work & Ergonomic Advantages of The New Improved Tools</u>

The farmers indicated that the tools helped to improve their quality of work (94.9 per cent) reported improved plant spacing (accuracy and plant population), improved ridge sizes and effective tillage and detailed weeding. The tools also helped them adopt new/better agricultural practices such as improved plant spacing and plant population management practices such as 1 seed planting (sasakawa) in maize, Diversification of crops such as adoption of legumes, sweet potatoes and irrigated vegetables as reported by 83 per cent and 17 per cent of the respondents respectively.

The hoes are light and less tiring, sharp and precise hence improved their quality of work in the field and made work easier and faster resulting in timely completion of agricultural tasks and timely planting with the first rains. This also gave them some time to rest and do other income generation activities. Some have adopted new crops such as Soy beans which is regarded as a "woman's crop" (main cash crop sold by women farmers) and has improved the amount of income controlled by the women in their families. Sharp and Light tools reduced the energy requirements for doing different agricultural tasks, reduced exhaustion and improved ergonomics which reduced back pains and muscle torn during field work. This improved the women's wellbeing and general health during the last two seasons they have used the tools.

The farmers covered larger pieces of land per day than before and could finish land preparation tasks on time which enabled them catch up with the onset of rains (early and timely planting). Field operations were completed effectively and efficiently because the tools were very light, sharp and reliable. Farmers indicated that they managed to finish their agricultural tasks much earlier than the last season using the existing tools.

As the agricultural extension officers recommend sasakawa planting, the farmers could adopt such practices as sasakawa planting (accurate spacing and 1 seed per station planting) with the help of the 2 sasakawa customized tools -1 blade sasakawa and the 3 blade sasakawa planting hoe which has customized precise plant spacing already set between the blades. The new planting tools enabled them to adopt sasakawa planting in maize production and legumes which increased their yields in the past season. Other climate smart agricultural practices adopted included using improved seed, drought and disease resistant seed, box ridging to conserve soil and water, winter cropping and irrigation plots to mention a few.

When the women farmers were further asked what they used the time savings for; they indicated that they could have some days off the field to rest as they finished the agricultural tasks earlier in readiness for the onset of rains. They also had enough time to do small businesses and could start backyard gardens for vegetables. The women farmers had enough time to take care of their families and spent more time with their children.

The feedback from women farmers was that the new tools were more durable compared to their existing tools and were more reliable since the blades did not bend during farm operation. In addition, the handles were always tightly fitted to the blades unlike their existing tools, as at times the blades come off the handles which also slows down work and is a safety hazard to the farmers. The new customized tools were also very sharp and did not need sharpening and repairs as the existing tools. Having these tools speed up their work as apart from slicing through the soil efficiently, soil did not stick to the blades as much as they did with existing tools which could make them heavier and waste time cleaning the blades. The new tools needed no repairs since they received them which saved the farmers time and money.

Gender and Women Empowerment

The impact of the tools on gender and women's empowerment was measured based on the following main domains of women empowerment: Group membership, leadership positions and public speaking. Based on the findings, the beneficiary women farmers have a 100 per cent group membership as they were all sampled from village savings groups and consumer producer groups described in chapter 2, page 31. The leadership empowerment domain was measured by comparing the level of comfort in public speaking between the beneficiary women farmers and the control cohort of women farmers. For the beneficiary group, 67 per cent indicated that they were "very comfortable" speaking in public about issues affecting their communities against 46 per cent for the control cohort demonstrating that in terms of leadership, the beneficiary women farmers are highly empowered. This can be linked to their level of involvement in the project which increased their levels of confidence during the co-design and testing stages of research which led to higher levels of empowerment as compared to those who were not part of the co-design and testing process.

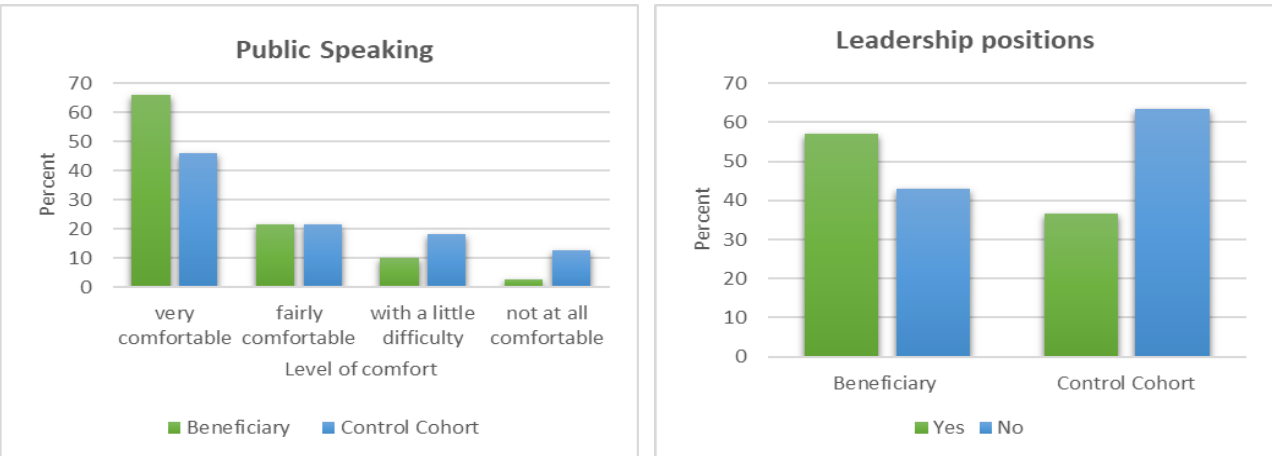

Figure 8-14 : Assumption of leadership positions and comfortability in public speaking

65 per cent) of the beneficiary women farmers indicated that they were "very comfortable" speaking in public on issues affecting their communities compared to 45 per cent for the control cohort group. They were all equally "fairly" comfortable speaking in public (20 per cent) but more women from the control group (12 per cent) reported that they were "not at all comfortable" speaking in public compared to

only 2 per cent of the beneficiary farmers who indicated that they were also "not at all comfortable" speaking in public.

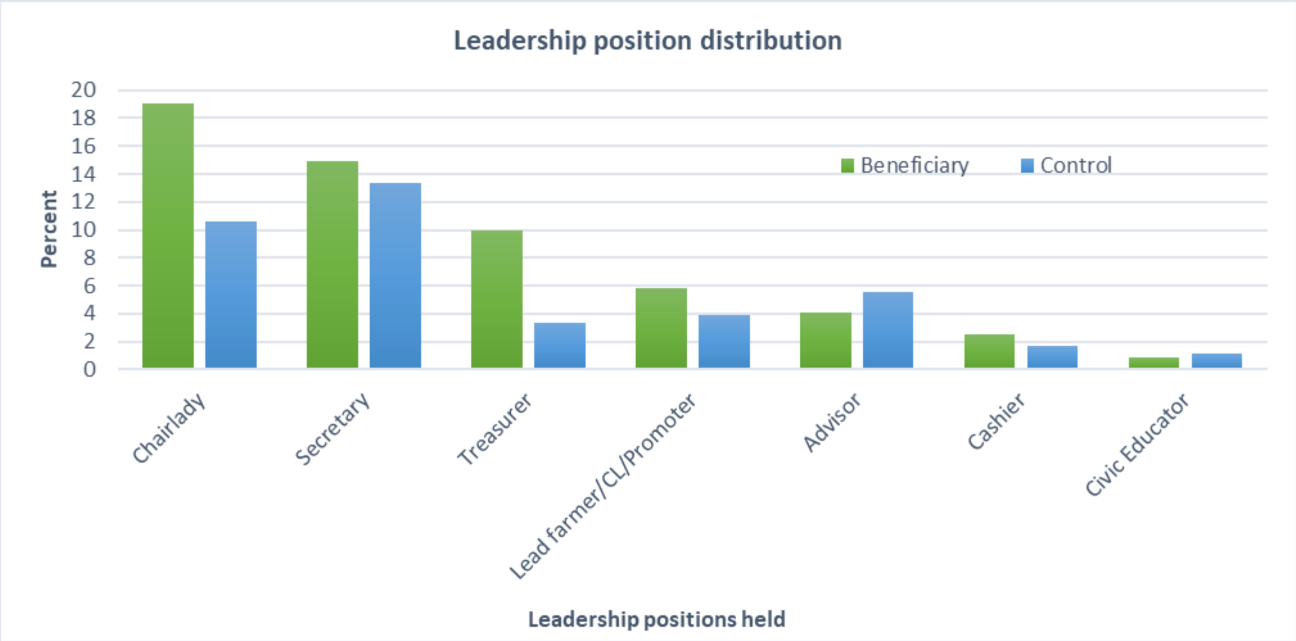

Figure 8-15: The common leadership positions assumed by the two sampled groups

There were differences in the type of leadership positions assumed by the beneficiary and the control groups interviewed. As displayed in the figure above, the beneficiary farmers tend to assume more influential leadership positions such as Chairlady, Secretary and Treasurer as opposed to the positions assumed by the control groups who are mostly members.

Decision Making During Production: Autonomy/input in decision making

Participation in decision making in agricultural production for the beneficiary women farmers indicated a higher level of empowerment through their involvement in the project. Most of the beneficiary women farmers indicated that they discuss with their spouses and contribute to a higher extent on decisions regarding agricultural production and crops/animals to grow.

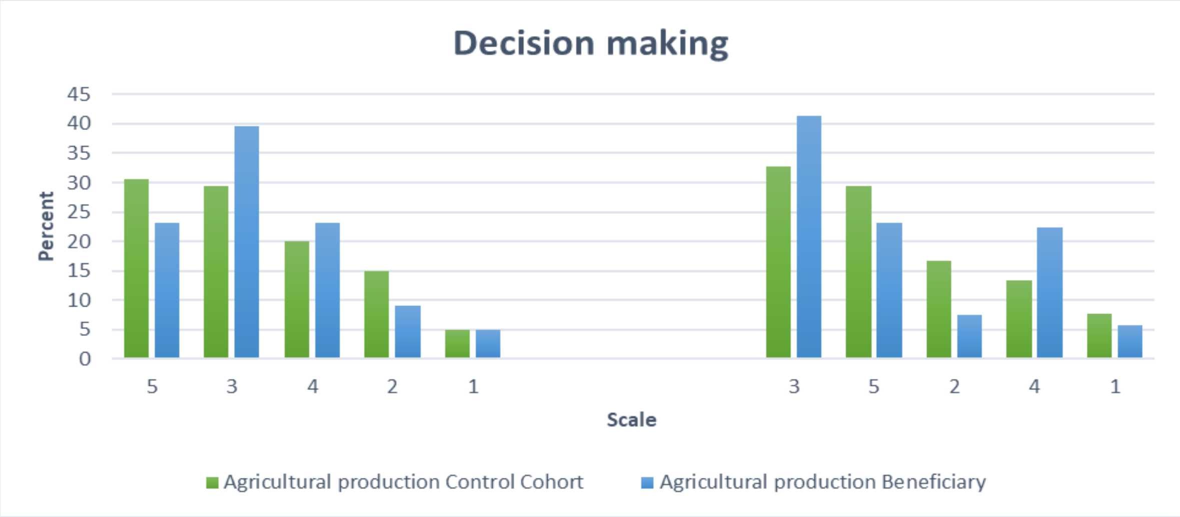

Figure 8-16: Participation in decision making regarding agricultural production

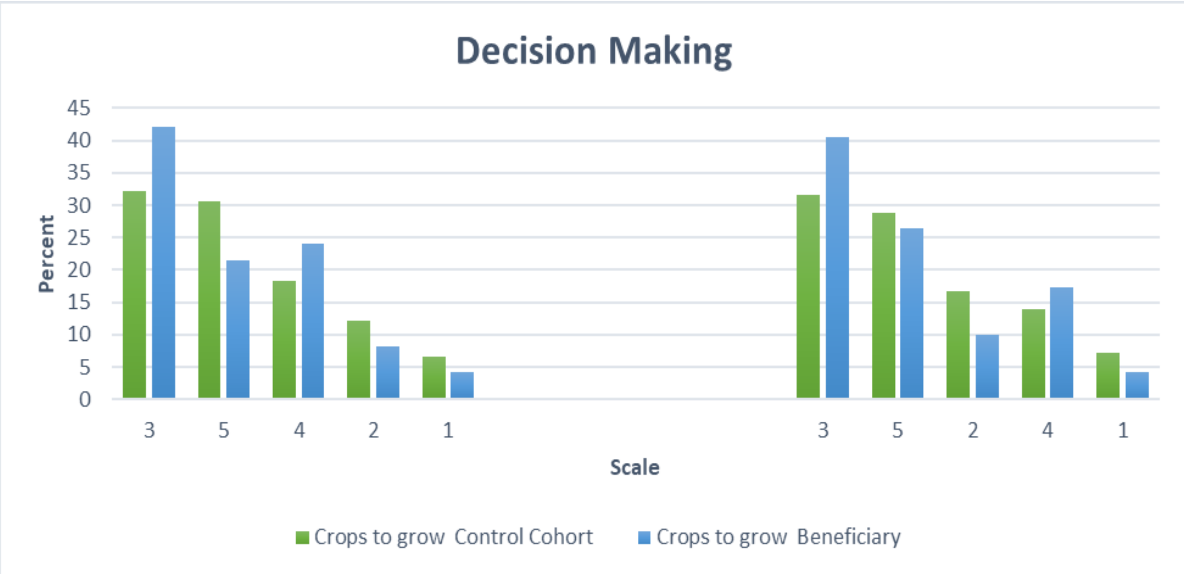

Figure 8-17: Participation in decision making regarding crops/animals to grow

<u>Resources: Ownership of assets and Access to Credit</u>

The results of the assessment indicate that the beneficiary women farmers are more empowered to have sole ownership of these tools as their resources and assets. The household ownership of assets is also better for the beneficiary households than the control group households. This can be attributed to higher innovativeness of the beneficiary women farmer households for example, trying new things including businesses, better agricultural practices and other income generating activities. The level of innovativeness was high for the beneficiary farmers based on the assessment done at the beginning of the project but it was clear to see that they have improved tremendously over the years of their involvement in the project against their own baseline.

Figure 8-18: Sole ownership of assets comparisons

highest owned sole assets for the beneficiary farmers are small livestock such as chickens followed by large livestock such as goats, pigs and cattle indicating a higher economic status. The livestock have also provided a stronger resilience to shocks. On the other hand, the highest solely owned assets for the control cohort is “Other” which was mostly specified as chicken utensils. Most of the women from the control group also indicated that they did not have sole ownership to any assets.

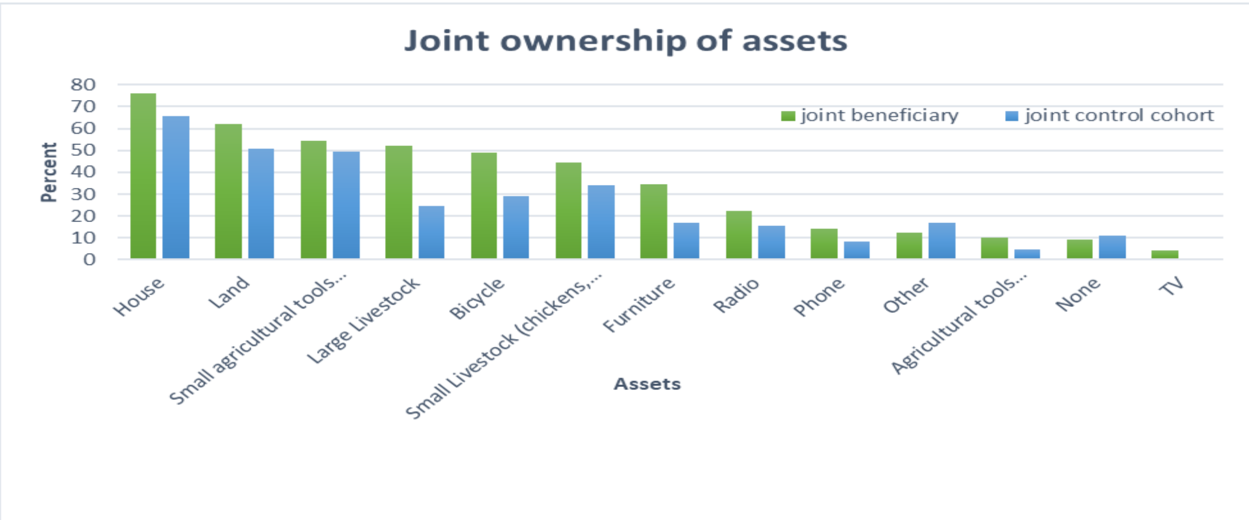

Figure 8-19: Joint ownership of assets comparisons

The highest jointly owned assets for the two groups was houses, land and livestock (both large and small livestock). These were all higher for the beneficiary households compared to the control groups. This indicates a better economic status and a higher economic empowerment through access to resources for the beneficiary group than the control cohort of households.

The beneficiary women farmers also demonstrated high level of impact from their participation in the program through their increased access to credit and loan facilities (71 per cent against 62 per cent) and 44 per cent indicated that they had taken an average of MWK60650.00 loan in the past year against only 28 per cent from the control cohort who managed to take a loan when they needed it in the past year. For the control cohort group, 22 per cent percent showed that they had no input in decisions regarding access to credit in their household. In terms of source of income diversification in the household (livelihood source), the women who tested the tools in the past season indicated that they had another business (63 per cent) apart from farming. There were some similarities in the common type of business done by the two groups sampled. Petty businesses (selling donuts etc.) and selling vegetables were reported by both groups as the most common business that they engage in. A good number also sell groceries and agriculture produce trading (livestock and grains) including selling dry fish.

For the women who do not currently run any business, Lack of capital was the main reason reported by both groups of sampled farmers and more women from the control cohort group indicate that they lacked skills to run a business (4 per cent) in contrast with 0.83 per cent for the beneficiary group. The two groups also reported the same businesses as common in their area and they both said they would rather do a different business than that which was common in their area. Further assessment on why they would rather do a different business, the beneficiary women farmers showed that they are driven by profitability in their selection of business followed by ease of management unlike the control cohort group which indicated that they are first driven by ease of management then profitability also revealing the high level of innovativeness with the beneficiary women farmers. There were significant differences in the monthly incomes, expenses and their current saving of the two sampled groups of women farmers with the beneficiary women farmers taking a lead in all the three categories as shown below:

Table 8-3: Average monthly income, expenditure and current savings

	Average Monthly income (MK)			
	Mean	**Median**	**Mode**	**SD**
Control cohort	14895.56	10000	10000	19619.95
Beneficiaries	35078.51	15000	10000	83825.81
	Average Monthly expenses (MK)			
Control cohort	13927.22	7000	5000	25457.34
Beneficiaries	30111.57	15000	10000	96098.79
	Current Savings (MK)			
Control cohort	27647.58	15000	20000	51370.83
Beneficiaries	90892.08	30000	30000	417187.9

There is clear indication of higher cash flows for the beneficiary women farmers than the control cohort which shows the impact of the women's involvement in the project and they improved livelihood from the tools design and testing process. The women farmer participants have also become role models in their villages as they have experienced high flows of other community members coming to ask advice from them. Out of the 121 beneficiaries sampled, 107 representing 88.43 per cent received other community members who came to ask for advice from them on new agricultural practices/techniques (40 per cent) and business management (20 per cent) against 58 per cent of the control cohort who are approached and asked about new agricultural practices/techniques and business management; 21 per cent and 23 per cent respectively.

Income: Control Over Use of Income and Productivity

The beneficiary women farmer's involvement in the project has brought about several positive impacts on the livelihoods and hence the economic income at household level. The beneficiary women farmers have reported a higher involvement in decision making regarding the purchase, sale, or transfer of land and assets such as agricultural tools. The beneficiary women farmers reported that they contributed to decision making towards agricultural production decisions to a "higher extent" (53 per cent) and 26.5 percent to a "medium extent". On the contrary, for the control group only 23 percent indicated that they contributed to decision making towards agricultural production in their household to a "higher extent" and 50 per cent to "medium extent". This is attributed to increased confidence towards the beneficiary women by their spouses since their involvement in the tools making process which has led to increased opportunity to input in decision making within the household.

The beneficiary women farmers also showed a higher involvement in decision making regarding decisions about the use of income generated from their farming and other income generating activities. The farmers who participated and tried the tools designed in the 3d4agdev program showed higher involvement in decision making on how to use the wages or salary from employment in all decisions (5/5)25.62 per cent, a very high extent (4/5) 32.23 per cent and to a medium extent (3/5) 30.58 per cent compared with the control cohort in all decisions (5/5)24.44 per cent, a very high extent (4/5) 22.78 per cent and to a medium extent (3/5) 26.67 per cent. The beneficiaries also indicated a higher participation in decisions regarding major and minor household expenditures, to a high extent (4/5) 30 per cent for the beneficiaries and 25 per cent for the control cohort group of women farmers.

We can therefore conclude that the beneficiary women farmers are more empowered in decision making regarding control over use of income, indicating a high impact from their involvement in the design and testing of the agricultural tools but also their contact with extension staff through the

3d4agdev program. This can be linked to the women's high time savings which has allowed them to do other income generating activities such as business but also income savings as describe below (table 4). Further inquiry also indicated that most of the assets by the beneficiary farmers have been acquired in the 2018/2019. A further study can explore this deeper to separate direct project participation benefits and other household improvements by chance.

There are many factors that come in play when it comes to improving quality of life. In agriculture, improved inputs are critical in improving production and in turn that improves the quality of life. In terms of improved agricultural inputs, there are many types and good tools are just part of it. The farmers reported increased yield (69 per cent) due to the use of the new tools because the new tools helped them increase land area cultivated which increased their yield. The tools also allowed them to adopt other new agricultural practices (52.5 per cent of the respondents). There are many improvements in the smallholder women farmers' quality of life developing from their participation in the program and use of the tools. Though some are direct, some were more secondary impacts.

Farmers noted improved incomes due to higher yields and money savings from reduced frequency of buying agricultural tools. The farmers reported an average MWK 79,120.19 (USD107.21) increase in income due to the use of the new tools. See the distribution of income increase in the figure below:

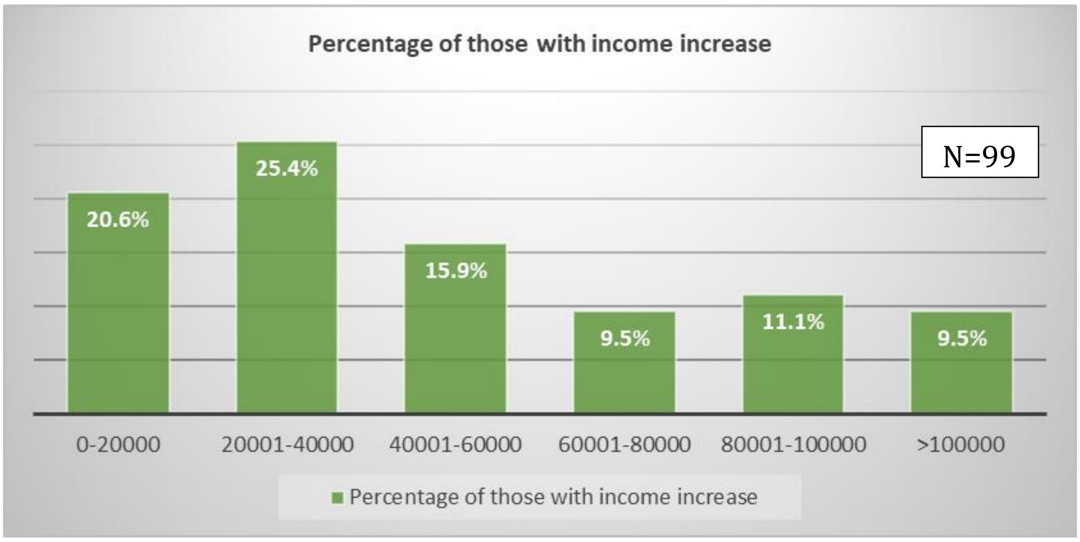

Figure 8-20: Income increase due to the use of the new hand-held tools

The income increase was also attributed to the time savings that gave them a chance to engage in small-scale businesses and irrigation farming. The figure below indicates the increase in yield especially for the maize crop (staple). On average the farmers managed a yield increase of 14.8 bags of maize weighing 50 kilograms.

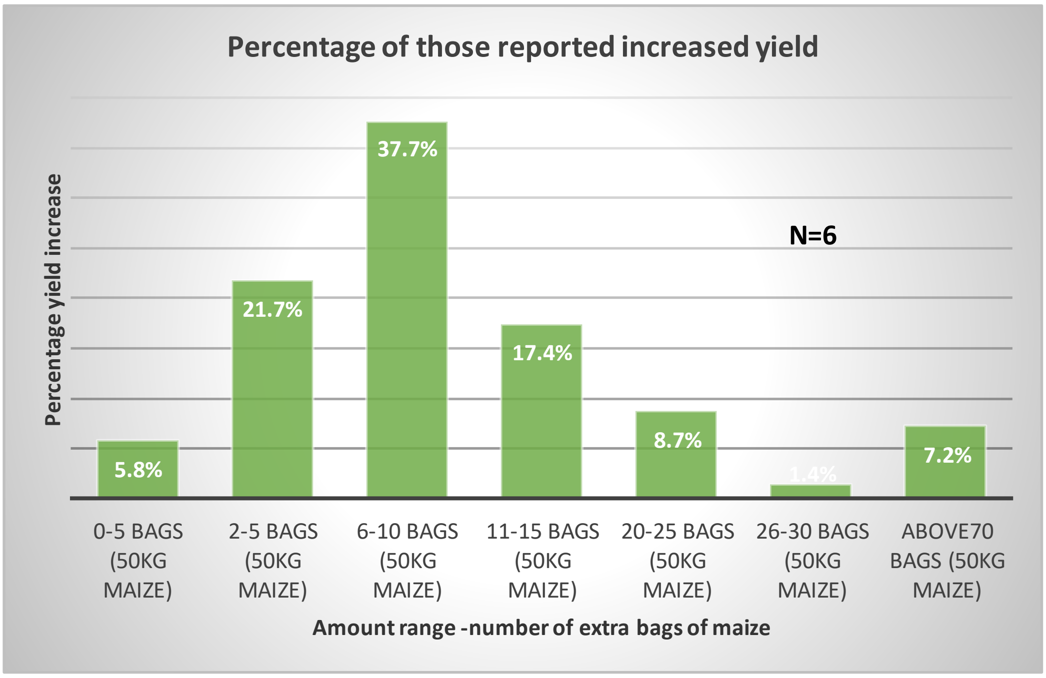

Figure 8-21: Increase yield due to the use of the new hand-held tools

The farmers reported that the new tools led to money savings for them (68.7 per cent) and the farmers saved on average MWK14454.05 (USD 19.59) because they did not need to buy hoes last season and will not procure new tools for the next season since the new tool kits are in superb condition. All the farmers interviewed indicated that the new tools were more durable than their existing tools. Due to the durability of the new tools, the farmers reported reduced frequency to replacing the hoes from every 2-3 years to every 4-6 years.

Farmers' Willingness to Buy Improved Hand-Held Agricultural Tools

All the beneficiary farmers demonstrated a 100 percent willingness to buy the tools if they were offered to them and 87 percent against 13 percent of the respondents indicated that other people in their community showed interest to also buy the tools. This was confirmed with the control cohort group of women smallholder farmers as 83 percent indicated that they were willing to buy the tools if available on the market against 9 percent who said would not buy and another 8 percent who were not sure if they could buy or not. The small percentage of people who indicated they would not buy was mostly because they regarded the tools highly and indicated the tools would be pegged at a price beyond their reach. The high percentage of respondents who showed willingness to buy the new tools indicates that there is a market for the customized tools and could be an opportunity for investment for tool manufacturers or other non-profit oriented companies that can be willing to increase access of these tools to smallholder farmers. The average prices indicated by the farmers can be used in calculations for gross margins and profitability of investing in mass production of the tools for sale. A further inquiry on how much the two groups would pay for the tools indicated relatively similar prices for the tools as shown in the table below:

Table 8-4 : Average prices in Malawi Kwacha (MK) for the tools across the 3 groups of samples indicating willingness to buy

Type of hoe	Beneficiary woman	Beneficiary woman's Spouse	Control cohort woman	Control cohort woman's Spouse	Extension staff
1 blade sasakawa	1117.79	1000.00	1064.67	900.00	1200.00
3 blade sasakawa	1922.60	3000.00	2058.77	2800.00	2500.00
Ridging hoe	2711.06	3000.00	2632.98	2700.00	2500.00
Clearing hoe	2197.12	2500.00	2047.13	2000.00	1900.00
Weeding hoe-Flat blade	2050.87	2000.00	1961.76	2500.00	3500.00
Weeding hoe-Wide blade	2045.19	2500.00	2206.73	2700.00	3000.00

Justifications for recommending the tools as indicated by the beneficiary women farmers was that the tools are light, save energy, are durable, reliable (sharp and stay intact when working with them) and improve their general farming experience with customized handles as there is reduced bending and hence less backaches i.e. improved health.

Changes in Attitudes and Behaviors

Farmers noted that since they participated in the research activities, they have an improved approach to their challenges including high level of innovativeness and approaching challenges differently in more efficient and unique ways. They felt more confident in doing things differently and consulted more with one another to solve their challenges within their community. The participation in the tool design sessions enabled them to gain improved problem-solving skills that boosted their confidence and left them feeling empowered to try and do more of new things to improve their lives.

The farmers' attitude towards farming using hand-held tools being exhausting has changed as the new tools brought excitement to farming in their villages. Up to 94.9 per cent of the farmers interviewed reported that the tools changed the way they work in their field. They reported that they completed farm tasks faster, improved the quality of their work and covered more land farming with the new tools as some tasks have become more exciting and fun to do due to reduced energy demands and exhaustion.

Changes in Community Participation Due to Participation in The Project and The Tools

Farmers from the innovator groups indicated that since their involvement in the research, they are now looked up to in the community and considered agents of change and great innovators. From the farmers interviewed, 64.6 per cent indicated that the tools improved their standing power in the community. The women farmers are seen as innovative and more exposed hence are considered more likely to provide solutions to different issues. The women smallholder farmers also reported that an increased number of people come to them to seek guidance/help on different challenges especially related to agriculture. The new tools are also in high demand at community level as relatives, neighbors and other community members borrow and use the new tools in their farms.

The women farmers also noted that within their own homes, they had increased their involvement in decision making in the household and were taking more leadership positions offered to the women farmers in the community. The women farmers are considered champions of change in the community. This has generally improved the community desire in participating in development projects as many members of the community want to be part of the research and other similar studies to provide sustainable benefits together with the target groups. The attitude of looking at short-term benefits in their participation in development projects has changed as a result of this research as most of the community members now mentioned both the short and long-term benefits from research as moving away from expectations of handouts and short-term gifts to looking forward to getting tangible and beneficial positive impacts within their household that are a direct result of their own contributions.

The farmers reported that other farmers within the community borrow their tools a lot and were worried that they might wear-out quickly. Within the household, there is high demand to use the new tools however they are not enough for each member. Another 1 per cent of the respondents indicated that they now have a better understanding of the intricate processes of technology development as the process of developing the tools was rather long and they spent a lot of time participating in focus group meetings and tool testing sessions to get the right design and outputs that suited their cropping systems. All in all, there is a great sense of ownership of the tools by the farmers as 61.6 per cent believe that the tools would have not been designed without their contributions. When asked to what extent they felt that they have contributed to the designing of the new tools, 65 per cent indicated to a great extent.

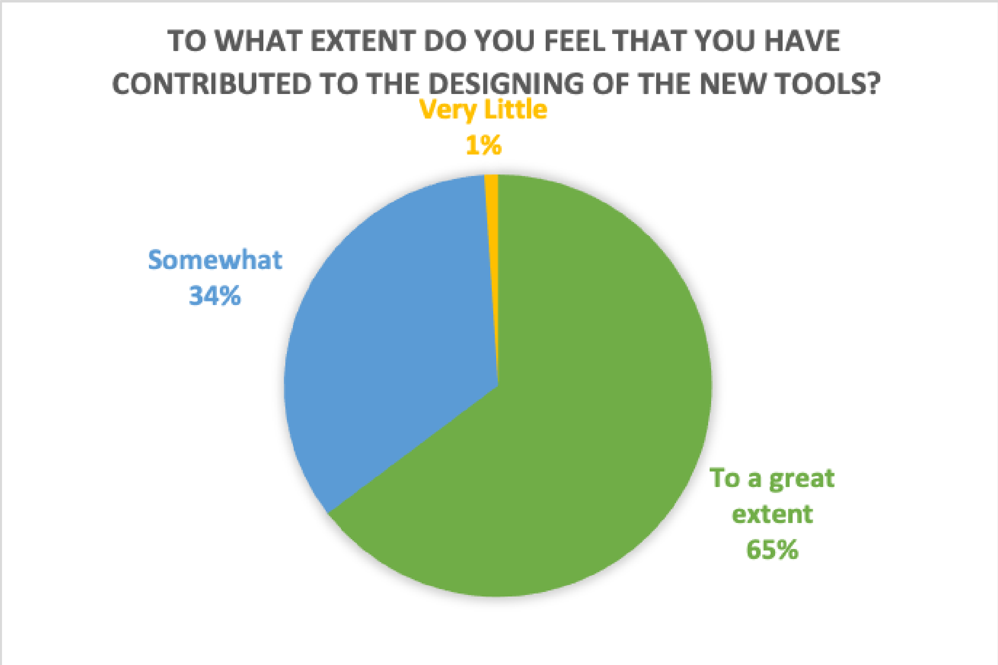

Figure 8-22: Women farmers' extent of contribution to the design of the new tools

Value of Tools Co-Designed by Women Innovators

When asked about the value of their tools and how much they could sell each of the tools developed including the post-harvest tools, the farmers indicated the average prices below:

Table 8-5 : Average tool prices for the hand-held tools as estimated by the farmers

Tools	MWK	Euro
Weeding hoe	1,845.92	2.50
Clearing hoe	2,103.06	2.85
Ridging hoe	2,751.02	3.73
Sasakawa (1 Blade)	1,085.71	1.47
Sasakawa (3 blades)	2,028.57	2.75
Weeding (wide blade)	2,133.67	2.89

For the hand-held tools, the farmers indicated that there is huge interest from other community members to access/buy the tools. When asked who they could sell the tools to if they got more, the farmers indicated as below: to their neighbors, their relatives and their friends.

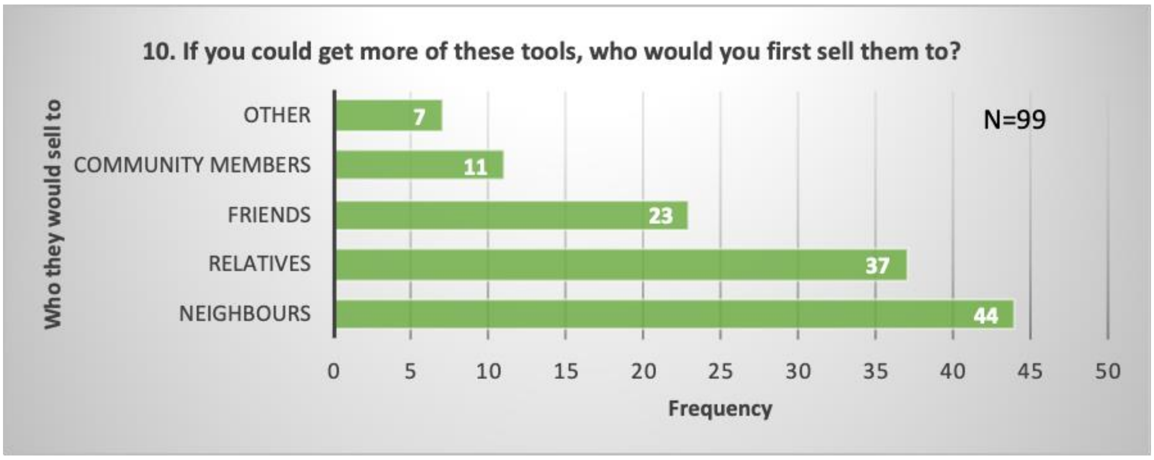

Figure 8-23: Who the farmer would first sell the hand-held tools to if they had more

They indicated they would first sell to the indicated groups as they have shown interest in the tools and also borrow their tools too much because they have seen the benefits of the new tools as compared to the existing ones.

Table 8-6 : Average tool prices for the post-harvest machines as estimated by the farmers

Types of P-harvest tool	**Tool Prices in MWK**	**Tool Prices in Euro**
Groundnut Sheller	165,697.67	224.52
Maize sheller	134,928.57	182.83
Maize grinder	190,166.67	257.67
Soya thresher	69,230.77	93.80

The farmers also reported that the post-harvest machines are more valuable than the hand-held tools as 73.7 per cent of the farmers indicated that it is more important to get access to the post-harvest tools because they could have huge impacts. The post-harvest machines could enable them more time savings, make work more-easier and they could hire them out to generate additional incomes for their post-harvest technologies as they are equally important and have different tasks they are developed for. The hand-held tools are used over a longer period during their rainy farming season as compared to the post-harvest tools that are more useful with large amounts during the harvest season.

<u>*Feedback from the Spouses*</u>

The assessment also involved getting feedback from spouses of both the beneficiary women farmers and the control cohort group. The spouses of the beneficiary women farmers had used the tools and indicated that they were used by the whole household. Feedback on the performance of the tools was not different from the reaction of the beneficiary women farmers. The spouses indicated that the tools were lighter, made agricultural tasks easier and saved them energy, needed no sharpening and saved their trees. It was also important to learn from the spouses that the new tools were easy to repair i.e. fixing and replacing the handles, they were more durable and the design was environmentally friendly as it used small pieces of wood for handles unlike the existing tools that require larger specific types of trees to make the existing handles. The men's first reactions on the tools was more on their durability, easy of repair and fixing of handles and their environmental friendliness mainly because of the gendered roles in their household as the tasks of repairing the tools was regarded as a male role. The men however also indicated that with the new handle design on the newly customized hoes, the women would also be able to fix the hoe handles and the hoes themselves whenever this was required which changed the gender norms in the household.

The spouses were happy to have their wives participate in a research that has empowered them to take up new great challenges in their households. The men supported their wives in the process by planning well to make sure their wives are free to attend the FGD sessions for the tool designs, dropped their wives at the sessions, provided monetary support and encouraged them to keep on participating in the meetings. The men also discussed with their wives about the design ideas when asked and about the probable tool designs that could be made. That also brought a great sense of ownership of the tool designs for the whole household. The spouses indicated that the tools improved household access to agricultural tools, improved their health and has changed their mindset towards the ability of their wives to take up roles that are regarded as for men. The community is also more willing to take part in development projects looking at long term benefits of their participation.

When asked about the challenges they faced using the tools, the men indicated that they did not encounter any major challenges using the tools except for some hoes, the handles became shaky with time. However, they managed to come up with solutions to the shaky handles by replacing the nails, replacing the handles to put in a thicker handle and by putting small pieces of wood in the space on the handle-blade connector. The spouse's recommendation was to involve more farmers in the project, make the improved hoes available on the market and to include other agricultural production techniques and inputs in the next programmes to come.

Feedback from Agriculture Extension Staff

Feedback was gathered from the agriculture extension staff who interacted with the beneficiary farmers in the research sites. The extension staff confirmed that the tools were in high demand by other farmers in the area, however, there is no access as they tools are not yet on the market. The farmers liked the tools because they were durable, lighter, easy to maintain and made farming work easier and faster. The sasakawa planting hoe were specifically indicated by most extension staff as very convenient, faster reliable and made easy for the farmers to maintain correct plant spacing. The extension staff especially in Nkhamenya indicated that some farmers complained that a lot of other community members were coming to borrow the new tools hence were afraid they will wear out faster. They therefore recommended that these improved cultivation tools be made available in the markets as there is high demand for them.

In terms of dissemination, the interviewed extension staff advised involving the innovator women farmers as sales agents/models in a lead farmer approach, identifying local outlets to sell the tools and displaying the new tools at field days and agriculture fairs for awareness to a wider audience. The extension staff also hailed the approach used in the research as sustainable as it built a sense of ownership involving the farmers throughout the process and changed the whole perception on getting short term project benefits during meetings to looking at the long-term benefits with their active engagement. According to the extension staff that were interviewed, the active involvement of women farmers in the innovation process also brought familiarity of the farmers to the new technology, ensured the adoption of the new improved tools as the new designs were compatible with the local conditions and cropping systems. They indicated that it is easy to interact with the farmers in the areas as their mindset towards research and development initiatives has changed since they were engaged in this study. For future research, the extension staff also recommended involving the spouses more, scaling up to more farmers, integrating with other agricultural production inputs such as seed and fertilizer (especially Integrated Soil Fertility Management services) and involving extension staff at all levels for sustainability of the research interventions.

8.5 Discussions and Conclusions

The comparison between the baseline and endline survey results indicates a marked improvement in the group of women farmers who now feel they have input into all decision-making abilities regarding agricultural production. There were fewer respondents from the endline survey who indicated that the decision was jointly made by both partners compared to the baseline survey indicating increase in autonomy for women smallholder farmers.

The endline survey results indicate that more of the women smallholder farmers are now part of the decision making process regarding the purchase of tools and inputs as recommended by (Ornetzeder and Rohracher, 2006, Alkire et al., 2013). In addition, no one in the endline survey indicated that they felt they had no decision making abilities regarding the purchase of tools and inputs. (Ornetzeder and Rohracher, 2006) also reported similar findings, but the women farmers' level of empowerment in the study area seems to have increased as a result of their engagement in the labour-saving technology development discussions and activities. This reflects a change in the household gender roles and can be attributed to the fact that the women smallholder farmers tool part in tool development processes and are now more knowledgeable. Their spouses may now feel that their wives are now capable of making sound purchases for on-farm tasks. Thus women empowerment through feminizing management of the farm, which is a condition when the women increasingly become primary decision makers on the farm (de Brauw et al., 2008, Murray, 2015, Alkire et al., 2013).

The number of respondents who indicated that they now can make all decisions regarding what crops to grow increased significantly by the end of the participatory women-farmer engaged research activities (Alkire et al., 2013, Ornetzeder and Rohracher, 2006). The women farmers participated in various research activities that gave them a greater understanding of their previously unrecognized contributions. The research engaged them as key farming experts and asked for their value adding inputs using PRA tools in focus group discussions (Farrington, 1998, Gonsalves et al., 2005, Lilja et al., 2001). These included seasonal/cropping calendar identification, activity clock breakdown of daily activities as well as the tool assessment exercises.

In both the baseline and endline, no one indicated that they had no decision-making abilities. This highlights that perhaps the "best-bet" innovators who were selected for the research already had higher levels of empowerment as compared to the remaining unselected women farmers. However, the focus group discussions demonstrated that some of the women were natural public speakers and were able to control the conversation while others were timid and tried to remain silent during the discussions. They were engaged effectively to actively listen and share their contributions with the rest of the group to brainstorm ideas for labour saving innovations. This could be a key to ennable women involved in policy making as it is rarely the case in many countries to have the voise of women since their needs are generaly neglected (Gawaya, 2008, Farrington, 1995).

The endline results indicate that more of the women smallholder farmers feel they are now part of the decision making process regarding timeline and person responsible for accessing markets to sell their farm produce (de Brauw et al., 2008). This highlights the need for extension advisory services to be gender sensitive and incorporate gender indicators to ensure they are engaging women farmers and supporting them to securely access markets (Farrington, 1995, Chambers and Jiggins, 1987, Röling et al., 2004). The results of the evaluation indicate that there is a change in the household gender roles and can be attributed to the fact that through the research involvement, the women smallholder farmers are now more knowledgeable and confident. Their spouses may now feel that their wives are now capable of selling their crops at a good price for the benefit of the whole household.

The results of the endline survey further show that the number of respondents who felt they could only participate in general household decision making to a "medium extent" has significantly decreased compared to the baseline results. This indicates that compared to before the research started, fewer of the women farmers feel they need approval from their partners to make these decisions. The results of the endline survey indicate that the number of respondents who were of the opinion that they could participate in all general household decisions to a “high extent” has doubled. This highlights the higher levels of decision making abilities perceived by these respondents (de Brauw et al., 2008, Alkire et al., 2013, Sraboni et al., 2014). The research emphasized the farmer as the “expert” and challenged the women farmers to value themselves and their experience in farming- related activities. This may have impacted them in a positive way that made them review their currently assigned roles and what else they felt they could do that was more productive for themselves and their households.

According to the results presented, the number of respondents who indicated that their extent of decision making regarding land and assets was “high” almost doubled. There was also a decrease in the number of respondents who indicated that they felt they could only make decisions to a “medium” extent and a “small” extent. These results of the endline highlight the changes gender roles in decision making regarding the purchase, sale or transfer of land and assets, and therse results agree with what was observed by (Murray, 2015, Alkire et al., 2013). These findings indicate that the women smallholder farmers now feel more confident in their ability to make contributions in their households as a result of their involvement in participatory group activities where they were with their peers and encouraged to speak up. It also suggests that women farmers feel more ownership of their household farm land and assets when they understood the critical labour contribution they made to caring for both farm land and all other assets, where culturally permitted. Research has shown that women’s productivity is less than that of their spouse because rarely do they have the same kind of access to tool, inputs and support systems to boost their agricultural productivity. When the women are engaged and supported adequately, they feel more empowered and recognized as equal contributors to their overall household well-being.

The findings on decision making regarding income use show a significant increase in the number of women farmers who feel that they now have input into all the decisions made regarding use household income generated from farming and other activities as also observed by (Murray, 2015, Alkire et al., 2013). The respondents indicated feeling entitled to decision making as they contributed to the generated of some or in other cases, all the income. esponses from the baseline and endline survey indicate a significant increase in the representation of women farmers who felt they can make all the decisions regarding the use of their personal wages or salary employment. The endline results also highlighted that not a single woman farmer felt she could not make decisions about her wages if she wanted to, findings supported by Murray et al based on this research on climate smart agriculture constraints (Murray, 2015). This indicates increases in the levels of empowerment for some of the respondents. The respondents who indicated that they felt they could only make some of the decisions decreased from 5 per cent to 1 per cent in the endline. This may be a result of women now making most or all the decisions regarding their wages or salary and could also indicate higher levels of empowerment among the women farmers the research worked with. Through the research activities, the women farmers understood their role in the labour force and how much their time is really worth. The women farmers' responses indicate that they now value their time more and the income generated from their own activities demonstrates the value of their time. They therefore feel most equipped to decide how their income should be spent (Guest and Swift, 2008, Alkire et al., 2013, Murray, 2015).

The endline results showed a decrease from the baseline survey as it did not have any women farmers who indicated that they felt they did not have any input in decisions made regarding major and minor household expenditures (Sraboni et al., 2014). In addition, 50 per cent of the women farmers indicated that at the time of the impact survey, they had all the decision making abilities regarding their household expenses. This is a improvement from the baseline period where only 22 per cent of the women responded the same. Since the number of responses indicating both partners decide decreased, this may reflect on the increase in women farmers' autonomy in decision making regarding household expenditures.

Although this research did not incorporate access to credit interventions, it was important to note this component in measuring the women farmers' level of empowerment in this regard (Alkire et al., 2013, Sraboni et al., 2014). The endline results show a sharp decrease in the number of respondents who indicated that they felt they have input into some of the decisions made regarding access to credit. Even more concerning is the difference noted between the respondents who felt they have input into all decisions regarding access to credit. However, endline results indicate that not a single woman farmer has input into these kinds of decisions now. In addition, while baseline results indicate that only 1 per cent had no input in decision making on credit access, endline results indicate that 48 per cent of them now indicate no input into decision making on access to credit. On the other hand, as all these farmers are in village savings and loans groups (VSL) (Hendricks and Chidiac, 2011, Karlan et al., 2017), the results of the endline in this regard are a little contradictory as the women farmers have access to low interest or no-interest loans in this VSL groups. The women farmers' expectations may have negatively affected their responses to this question or they may have incorrectly assumed that those who indicated that they have no access to credit would lead to this research creating access to credit.

Endline survey results compared to baseline indicate that more women farmers have taken on leadership roles as a result of being designated as women with high innovation potential, and being involved in the project. In addition, working with their peers in the co-design and field testing sessions and presenting their ideas to a group also contributed to the higher levels of confidence to take up leadership roles. This signifies an increase in their levels of empowerment as a result of their involvement in the group-based research activities where they became adept at sharing their ideas and contributions and defending their opinions in a constructive way. The endline results indicated that one of the women farmers became a chief during the time she was involved in the participatory research activities. There were no chiefs indicated in the baseline survey results. While the results of the baseline survey conducted before the research did not have any results for lead farmers, based on the endline survey results, 6 per cent of the respondents indicated that they were now lead farmers which is an indication of empowerment (Sraboni et al., 2014, Alkire et al., 2013, Murray, 2015). This change occurred during their involvement in the research activities where they were always encouraged to share their opinions and demonstrate the farming activities during the focus group discussions.

The results indicate an increase in the number of respondents who feel very comfortable speaking in public regarding community issues. There was a slight improvement among the respondents who indicated that they can speak publicly “with a little difficulty”. This may be as a result of more women feeling comfortable with public speaking as a result of them practicing during the research FGDs.

In general, the overall involvement of women farmers as innovators through the various phases of the innovative research process enabled them to be listened to and participate, to be appreciated by their peers and the research team. The effect of engaging with the women explicitly as best-bet innovators played a pertinent positive role in shaping the women’s attitudes towards the research and the design process to view themselves as active actors, contributors and not simple recipients of innovations produced elsewhere without their interests in mind. It changed the mindset of the participants as well as their spouses. The control group participants expressed interest to participate in similar research as they indicated that the women innovators have “changed” for the better, are more “present” in the community as advisors and role models who can change their own circumstances and take ownership of their challenges to jointly find solutions with other women farmers in their villages. This played the ultimate role of empowerment as per the women farmers who participated in the research and was therefore a key success for the research in the end.

9. RESEARCH CONCLUSIONS

The innovation identification process was pertinent for this research as it was one of the tenets this PhD study aimed to assess among women farmers who were in innovator groups. The identification of innovators was crucial for the tool co-design, prototyping and took testing and therefore required careful assessment of the rural-based women smallholder farmers. The innovator potential does exist and should be further strengthened to develop the evidence base regarding the successes that can be gained by identifying innovators within the rural context who can contribute to the technology research and development process. The innovation assessment conducted formed the basic tenet for the innovation process this research set out to pilot and analyze. The identification of the (best-bet) innovators involved the design of the detailed innovation questionnaire that took into context the rural setting the survey was conducted in and probed through closed ended and open questions to identify innovative responses. It is important to note that the selection process took some time as it was the most crucial aspect of the research; to test innovation potential towards agricultural tools for labour intensive tasks identified by women farmers.

The procedure for selecting women as “best-bet innovators” formed the basis for this research on bottom-up approaches to agri-technology development and aimed to identify women farmers who, in spite of their low income and resource limited environment, have the innovative capacity to share their contributions in an open and inclusive innovative creative space that was provided by the research. The sampling method involved a combination of deductive and inductive elements where the target innovator was a female smallholder farmer first and an innovative one who could be grouped with other similar/likeminded, confident women. The research considered criteria that would remove any bias in selection of the women farmers to be involved in a participatory design/innovation process. The aim of the study was to identify innovators among the marginalized and excluded “poorer” and disadvantaged farmers who are systematically left out of the innovation cycle in the technology AR4D process. The research aspires to overcome these systemic challenges and directly targeted women smallholders’ farmers from a low income, resource limited, unmechanized agricultural context.

The innovation screening criteria developed by this research was instrumental in identifying the “best-bet” innovators among women smallholder farmers and once these innovator groups were identified, the research assessed the agricultural tasks prior to the technology design process to better understand what the labour constraints are for the women farmer innovators. This further enabled the research to identify and focus on the key agricultural tasks that the women farmers categorized as highly labour intensive. As a result, a ranking of highly labor-intensive agricultural tasks was developed for both the cultivation season and post-harvest activities. Based on these rankings, together with the women innovators from the farming community, resources were also investigated to capture the human and other resources that were available to the women farmers and their communities. These resources were identified in order to better understand any limitations that would create bottlenecks in the technology development process involving the women innovators.

Once these resource limitations were identified, the research was able to work with the innovator groups to determine the best of what was available to be used for the technology co-design process. In addition, the resource maps also enabled the research to identify local entrepreneurs who could support the technology development process using locally available materials. This further boosted the local capacities to produce locally for local use. This also empowered the women farmers who felt confident in their ability to identify the resources needed for the technology development process to speed up local manufacturing of agricultural tools that were labour saving and ergonomically suited to their needs.

Throughout all the co-design processes, the innovative thinking capacity of the female farmers was evaluated to ensure their contributions were feasible and applicable to the research. In phase I, the co-design process took the women innovator groups through creative discussion sessions where 2D sketches were developed using flip charts, markers and other documentation instruments such as photos and video recordings. These 2D sketches were then translated into 3D renders using CAD software which were then used to produce the 3D micro prototypes. Local artisans were engaged and using the printed 3D prototypes, tools to be tested were produced using locally available scrap metal. In phase II, to further compare the durability and weight of the tools, the study decided to improve the tools further by developing metal cast tools. This idea was supported by findings of (Klobčar et al., 2007) who reported superior resistance in metal cast tools than welded tools. Based on the results of this co-design process and field testing process, it can be concluded that the selected women smallholder farmers are innovative as this group of "best-bet innovators" successfully co-designed tools for their labor-intensive agricultural tasks, tested both the newly produced tools in comparison to the existing tools and methods and were key players in the final production of the new and improved tools based on evidence collected. At this stage of the research, it was noted that through this bottom-up participatory approach and given the existence of enabling creative spaces and resources, selected cohorts of women smallholder farmers with innovative capabilities can and should be engaged to successfully steer the process to develop innovations that are useful in addressing the labour constraints of farming activities.

The findings enabled the research to make the argument that for technologies to address target groups' needs/demands, women smallholder farmers need to be included and that their ideas must be taken into consideration during the research and development process for each agricultural technology to be introduced into their markets. Women smallholders and local tool producers must be better equipped with knowledge and skills on how to improve their agri-tools and implements to incorporate time and labour saving strategies. The next chapter provides details of the on-farm time differential trials that were conducted to compare the prototypes produced in this chapter to the existing tools found in the researched areas of rural Malawi.

During the trials, this research demonstrated that wearable kinematic sensors when utilized accurately, can provide opportunities for indirectly measuring energy exertion for different human movemements, including agricultural tasks. Although the energy savings demonstrated were not statistically significant, considering that these were experimental tests using kinematic sensors tailored to the sports sector and not the agricultural tools, the improved tools demonstrated some potential to save time and energy for the end-user which ultinately is the desire of the smallholder farmers. Considering the challenges noted, the time and energy savings captured may potentially have been much more significant if the technical issues were absent. A key lesson learned using the Shimmer sensors is that the instruments applied must be adapted for on farm testing considering the challenges noted. A follow-on research on this would add value to this discussion in the future. In addition, as indicated in chapter 6, all the women's innovator groups highly expressed their preferences for the newer tools as they were lighter, more contemporary and customized and in general, were safer and better tools to use. The innovator groups expressed an interest in and willingness to buy these tools should they be made available in the market. As a result, the research conducted the market study to better review the availability, willingness to buy for other farmers not included in the research.

As outlined in Chapter 7, the results of the market assessment indicate that there is no shortage in the number and types of sellers of hand-held agricultural tools for smallholder farmers in Malawi but rather in the availability of good quality technologies After careful observation of the retailers and local producers as well as through informal discussions with farmers within the study sites, the main obstacles to being able to provide quality and affordable labour-saving tools is the lack of funds to produce improved tools as well as the lack of awareness of improved labour-saving farming tools (Siqwana-Ndulo, 2007) (Ferreira, 2018). The best distribution channels for improved tools will need to be within close proximity of the farmer's households and be affordable to them as farmers usually have to walk many hours to get to their markets where the costs are not within their reach. By concentrating on locations that farmers can easily access, dissemination strategies can be put in place for sustainable distribution of these tools. This is of course with the understanding that mutual collaborative agreements can be made with the EPAs, NGOs and FOs to partner in the dissemination and training of new and improved farmer-designed agricultural tools for farming activities in Malawi.

Given the adequate amount of financial resources and technical support, distribution and sales of improved hand-held farming tools can be made more accessible by youth entrepreneurs interested in venturing into "more lucrative aspects" of agriculture than farming by becoming sellers of improved tools. These additional investments into the market development would ensure that adequate supply of customized hand-held tools is made available to the communities in need at an affordable cost. The willingness to buy was confirmed by the women innovator groups as well as by participants of the market assessment considering the costs of the tools as well as the labour and energy savings.

The beneficiary women farmers had a great experience using the customized hoes in their farms for the first time. The hoes helped them save time and energy which helped them have enough time to rest, take care of their families and cover more land for in their fields. The impacts on their livelihoods were massive as the time to do business enabled them to improve their economic traditional s and improved health and wellbeing. The women were more empowered to try new things including adopting new agricultural practices and technologies which has improved their yield over the year. The demand from the non-beneficiary control cohort group to be part of the program also indicates the need for the massive rollout of the tools to expand the program to more farmers within the target areas and other districts. This expectation should be met by exploring various avenues to source funding for scale up and continuation of the research program to ensure that the post-harvest technologies are available for the smallholder farmers.

To summarize, this PhD research successfully tested the hypothesis presented which is whether women farmers in developing contexts have the potential/capacity to design technologies tailored to their cropping systems. The evidence presented in this 8-chapter thesis is that women farmers are capable innovators who can be engaged as users of technologies to provide much need value added ideas to the agricultural technology development initiatives. This, the author argues, is the most beneficial and sustainable approach to ensure long-term technology enhanced impacts reach the target groups. Furthermore, these technologies have the potential to distribute labour more equitably and evenly among rural households, considering that gender roles are changing in Malawi and other similar developing contexts. These technologies have and can facilitate gender equity discussions to help close the gender gap noted in the agricultural sector. Further research on this would add value and knowledge and enhance understanding of all stakeholders and policy makers involved in strategic policy and program development for emerging economies.

10. REFERENCES

AAS, T. H. & BREUNIG, K. J. 2017. Conceptualizing innovation capabilities: A contingency perspective. Journal of Entrepreneurship, Management and Innovafion, 13, 7-24.

ADESINA, A. A. & ZINNAH, M. M. 1993. Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. Agricultural economics, 9, 297-311.

AGUILAR, A. A., GOLDSTEIN, M. P., KILIC, T. & OSENI, G. 2014. Decomposition of gender differentials in agricultural productivity in Ethiopia. World Bank Policy Research Working Paper.

AIKINS, S. H. M. 2010. PERFORMANCE EVALUATION OF JAB PLANTERS FOR MAIZE PLANTING AND INORGANIC FERTILIZER APPLICATION. APRN Journal of Agricultural and Biological Science, 5.

ALENE, A. D. 2010. Productivity growth and the effects of R&D in African agriculture. Agricultural Economics, 41, 223-238.

ALENE, A. D. & COULIBALY, O. 2009. The impact of agricultural research on productivity and poverty in sub-Saharan Africa. Food Policy, 34, 198-209.

ALTIERI, M. A., FUNES-MONZOTE, F. R. & PETERSEN, P. 2012. Agroecologically efficient agricultural systems for smallholder farmers : contributions to food sovereignty. Springer, 32, 1-13.

AQUASTAT. 2005. MALAWI: Geography, climate and population. Available: www.fao.org/nr/water/aquastat/countries_regions/MWI/MWI-CP_eng.pdf [Accessed 06 July 2018].

ADESINA, A. A. & ZINNAH, M. M. 1993. Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. Agricultural economics, 9, 297-311.

AGARWAL, R. & SHAH, S. K. 2014. Knowledge sources of entrepreneurship: Firm formation by academic, user and employee innovators. Research Policy, 43, 1109-1133.

ALKIRE, S., MEINZEN-DICK, R., PETERMAN, A., QUISUMBING, A., SEYMOUR, G. & VAZ, A. 2013. The women’s empowerment in agriculture index. World Development, 52, 71-91.

ALY, H. Y. & SHIELDS, M. P. 2010. Gender and agricultural productivity in a surplus labor, traditional economy: empirical evidence from Nepal. The Journal of Developing Areas, 43, 111-124.

ASHBY, J. A. & SPERLING, L. 1995. Institutionalizing Participatory, Client-Dirve Research and Tech Development in Agriculture. Development and Change, 26, 753-770.

AAS, T. H. & BREUNIG, K. J. 2017. Conceptualizing innovation capabilities: A contingency perspective. Journal of Entrepreneurship, Management and Innovation, 13, 7-24.

ADEKUNLE, A., ELLIS-JONES, J., AJIBEFUN, I., NYIKAL, R., BANGALI, S., FATUNBI, A. & ANGÉ, A. Year. Agricultural innovation in ub-Saharan Africa: Experiences from multiple stakeholder approaches. In, 2012. Accra, Ghana: Forum for Agricultural Research in Africa (FARA).

ALKIRE, S., MEINZEN-DICK, R., PETERMAN, A., QUISUMBING, A., SEYMOUR, G. & VAZ, A. 2013. The women's empowerment in agriculture index. World Development, 52, 71-91.

ASHBY, J. A. & SPERLING, L. 1995. Institutionalizing Participatory, Client-Dirven Research and Tech Development in Agriculture. Development and Change, 26, 753-770.

BANK, T. W. 2016. MALAWI ECONOMIC MONITOR MAY 2016, ABSORBING SHOCKS,

BANK, T. W. 2017. New Policies to Help Transform Malawi's Agriculture Sector [Online].

BANK, W. 2014. Levelling the Field: Improving Opportunities for Women Farmers in Africa.

BAO HUY, V. H., HOANG HUU CAI 2002. Helvetas: Participatory_Technology_Development_Handbook. Social Forestry Training Network.

BASU, R. R., BANERJEE, P. M. & SWEENY, E. G. 2013. Frugal innovation: core competencies to address global sustainability. Journal of Management for Global Sustainability 1 63 – 82.

BECKFORD, C., BARKER, D. & BAILEY, S. 2007. Adaptation, innovation and domestic food production in Jamaica: Some examples of survival strategies of small-scale farmers. Singapore Journal of Tropical Geography, 28, 273-286.

BELLOTTI, B. & ROCHECOUSTE, J. F. 2014. The development of Conservation Agriculture in Australia—Farmers as innovators. International Soil and Water Conservation Research, 2, 21-34.

BOEHLJE, M. & BRÖRING, S. 2011. The increasing multifunctionality of agricultural raw materials: Three dilemmas for innovation and adoption. International Food and Agribusiness Management Review, 14, 1-16.

BOGERS, M., AFUAH, A. & BASTIAN, B. 2010. Users as Innovators : A Review , Critique , and Future Research Directions. Journal of Management and Sustainability, 36, 857-875.

BRUNORI, G., BARJOLLE, D., DOCKES, A. C., HELMLE, S., INGRAM, J., KLERKX, L., MOSCHITZ, H., NEMES, G. & TISENKOPFS, T. 2013. CAP reform and innovation: the role of learning and innovation networks. EuroChoices, 12, 27-33.

BALIWADA, H., SHARMA, J., BURMAN, R., NAIN, M., KUMAR, A. & VENKATESH, P. 2017. Constraints and Strategies in Scaling up of Farmer-led Innovations. Journal of Community Mobilization and Sustainable Development Vol, 12, 72-78.

CHAMBERS, R. & JIGGINS, J. 1987. Agricultural research for resource-poor farmers Part II: A parsimonious paradigm. Agricultural Administration and Extension, 27, 109-128.

CHAMBERS, R. 2014. Rural development: Putting the last first, Routledge.

CHAMBERS, R. & GHILDYAL, B. 1985. Agricultural research for resource-poor farmers: the farmer-first-and-last model. Agricultural administration, 20, 1-30.

CHESBROUGH, H. 2003. The logic of open innovation: managing intellectual property. California management review, 33-58.

CRITCHLEY, W. 2000. Inquiry, initiative and inventiveness: farmer innovators in East Africa. Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, 25, 285-288.

DETHIER, J.-J. & EFFENBERGER, A. 2012. Agriculture and development: A brief review of the literature. Economic Systems, 36, 175-205.

DOLORES, M. & TONGCO, C. 2007. Purposive Sampling as a Tool for Informant Selection. Journal of Agriculture Education, 5, 147-158.

DOOLEY, K. E. 2006. VIEWING AGRICULTURAL EDUCATION RESEARCH THROUGH A QUALITATIVE LENS. Journal of Agriculture Education, 48, 32-42.

DOUTHWAITE, B., KEATINGE, J. & PARK, J. 2002. Learning selection: an evolutionary model for understanding, implementing and evaluating participatory technology development. Agricultural Systems, 72, 109-131.

DETHIER, J.-J. & EFFENBERGER, A. 2012. Agriculture and development: A brief review of the literature. Economic Systems, 36, 175-205.

DOSS, C. R. 2001. Designing Agricultural Technology for African Women Farmers: Lessons from 25 Years of Experience. World Development, 29, 2075-2092.

DOSS, C. R. 2010. If women hold up half the sky, how much of the world's food do they produce? ESA Working Paper, 11.

FAGERBERG, J. 2003. Innovation : A Guide to the Literature. Centre for Technology, Innovation and Culture, University of Oslo.

FURSOV, K., THURNER, T. & NEFEDOVA, A. 2017. What user-innovators do that others don't: A study of daily practices. Technological Forecasting and Social Change, 118, 153-160.

GAWER, A. & CUSUMANO, M. A. 2014. Industry Platforms and Ecosystem Innovation. Journal of Product Innovation Management, 31, 417-433.

GLOVER, D., SUMBERG, J. & ANDERSSON, J. A. 2016. The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. Outlook on agriculture, 45, 3-6.

GLOVER, D., SUMBERG, J., TON, G., ANDERSSON, J., & BADSTUE, L. (2019). Rethinking technological change in smallholder agriculture. Outlook on AGRICULTURE, 48(3), pp. 169-180.

GONSALVES, J., BECKER, T., BRAUN, A., CAMPILAN, D., CHAVEZ, H. D., FAJBER, E., KAPIRIRI, M., RIVACA-CAMINADE, J. & VERNOOY, R. 2005. Participatory Research and Development for Sustainable Agriculture and Natural Resource Management: A SOURCEBOOK. Ottawa, Canada and Rome, Italy.

GUPTA, A. K., SINHA, R., KORADIA, D., PATEL, R., PARMAR, M., ROHIT, P., PATEL, H., PATEL, K., CHAND, V. & JAMES, T. 2003. Mobilizing grassroots' technological innovations and traditional knowledge, values and institutions: articulating social and ethical capital. Futures, 35, 975-987.

GUSTAFSSON, A., KRISTENSSON, P. & WITELL, L. 2012. CUSTOMER CO-CREATION IN SERVICE INNOVATION – A MATTER OF COMMUNICATION ? . Journal of Service Management.

HILDEBRAND, P. E. & PARTENHEIMER, E. J. 1958. Socioeconomic characteristics of innovators. Journal of Farm Economics, 40, 446-449.

HOUNKONNOU, D., KOSSOU, D., KUYPER, T. W., LEEUWIS, C., NEDERLOF, E. S., RÖLING, N., SAKYI-DAWSON, O., TRAORÉ, M. & VAN HUIS, A. 2012. An innovation systems approach to institutional change: Smallholder development in West Africa. Agricultural Systems, 108, 74-83.

HENDRICKS, L. & CHIDIAC, S. 2011. Village savings and loans: A pathway to financial inclusion for Africa's poorest households. Enterprise Development and Microfinance, 22, 134-146.

HOSSAIN, M. 2016. Grassroots innovation: A systematic review of two decades of research. Journal of Cleaner Production, 137, 973-981.

IFAD/FAO/FARMESA The potential for improving production tools and implements used by women farmers in Africa-Zambia. Joint IFAD/FAO/FARMESA Study.

JANSZEN, F. 2000. The age of innovation. Financial Times/Prentice Hall, London.

JENNINGS, J. 2005. On the Effectiveness of Participatory Research in Agriculture. University of Western Sydney.

JOHNSON, D. 2001. What is innovation and entrepreneurship? Lessons for larger organisations. Industrial and commercial training, 33, 135-140.

KARLAN, D., SAVONITTO, B., THUYSBAERT, B. & UDRY, C. 2017. Impact of savings groups on the lives of the poor. Proceedings of the National Academy of Sciences of the United States (PNAS), 114, 3079-3084.

KOGAN, L., PAPANIKOLAOU, D., SERU, A. & STOFFMAN, N. 2017. Technological innovation, resource allocation, and growth. The Quarterly Journal of Economics, 132, 665-712.

LAGNEVIK, M. 2005. Farmers as innovators. Lund Institute of Economic Research Working Paper Series.

LAKHANI, K. R. & PANETTA, J. A. 2007. The Principles of Distributed Innovation. innovations / summer 2007, 97-112.

LEHTO, P. 2012. <14 Action Plan for User-driven innovation_Petri Lehto(1).pdf>.

LILJA, N., ASHBY, J. & SPERLING, L. 2001. Assessing the impact of participatory research and gender analysis, Participatory Research and Gender Analysis (PRGA), Program Coordination Office; International Center for Tropical Agriculture (CIAT).

LOY JR, J. W. 1969. Social psychological characteristics of innovators. American Sociological Review, 73-82.

MACMILLAN, T. & BENTON, T. G. 2014. Engage farmers in research. Nature, 509, 25.

MAKATE, C. & MANGO, N. 2017. Diversity amongst farm households and achievements from multi-stakeholder innovation platform approach: lessons from Balaka Malawi. Agriculture & Food Security, 6, 37.

MITCHELL, V., ROSS, T., MAY, A., SIMS, R. & PARKER, C. 2015. Empirical investigation of the impact of using co-design methods when generating proposals for sustainable travel solutions. CoDesign. 1–16.

MOAIWD, M. G. 2016. National Agriculture Policy 2016.

MOORE, G. A. 1999. Crossing the Chasm, Marketing and Selling High-Tech Products to Mainstream Customer (revised edition), , HarperCollins Publishers, New York

MURRAY, U., GEBREMEDHIN, Z., BRYCHKOVA, G. & SPILLANE, C. 2016. Smallholder Farmers and Climate Smart Agriculture: Technology and Labor-productivity Constraints amongst Women Smallholders in Malawi. Gender, Technology and Development.

NEUVO, Y. & YLÖNEN, S. 2010. Bit bang II: Energising Innovation, Innovating Energy. Helsinki University Print 2010.

NIELSEN, K. R., REISCH, L. A. & THØGERSEN, J. 2016. Sustainable user innovation from a policy perspective: a systematic literature review. Journal of Cleaner Production, 133, 65-77.

NIOSI, J., SAVIOTTI, P., BELLON, B. & CROW, M. 1993. National systems of innovation: in search of a workable concept. Technology in Society, 15, 207-227.

OLIVEIRA, P. & HIPPEL, E. V. 2009. Users as Service Innovators : The Case of Banking Services Users as Service Innovators : The Case of Banking Services.

OLUSI, J. 1997. Enhancing Female Participation in African Agricultural Transformation: The Nigerian Experience. Issue: A Journal of Opinion, 25, 12-15.

OMOBOLANLE, L. 2010. Synthesis of extension models and analysis for sustainable agricultural technologies : lessons for extension workers in southwest , Nigeria . Agriculture and Biology Journal of North America, 1, 1187-1192.

PELLEGRINO, G. & SAVONA, M. 2017. No money, no honey? Financial versus knowledge and demand constraints on innovation. Research Policy, 46, 510-521.

PENIN, J. 2011. Open Souce innovation: Towards a generalization of the open source model beyond software. Levue Deconomie Industrielle, 136, 63-88.

PETRÍK, S., GARDIÁN, A. & LYBRAND, F. INOVATION AND BUSINESSIN NEW TECHNOLOGIES [Online].

Available: https://nanoed.tul.cz/pluginfile.php/4176/mod_resource/content/1/IPNT_1_EN.pdf [Accessed 01/05/2019 2019].

PIPER, N. 2005. Gender and migration; A paper prepared for the Policy Analysis and Research Programme of the Global Commission on International Migration. Available: http://incedes.org.gt/Master/pipersesentacuatro.pdf [Accessed 01/05/2019].

POIRIER, V., SCHWARTZ, L. H., EDDY, D., BERMAN, R., CHACOUR, S., WYNNE, J. J., CAVANAUGH, W., MARTIN, D. F., BYRNE, R. & SANBERG, P. R. 2017. Thoughts on Improving Innovation: What Are the Characteristics of Innovation and How Do We Cultivate Them? Technology & Innovation, 18, 319-330.

REGAN, J. A. C. 2016. Innovators and Early Adopters of Distance Education in Social Work. Advances in Social Work, 17, 113-115.

ROGERS, E. M. 1959. A note on innovators. Journal of Farm Economics, 41, 132-134.

ROGERS, E. M. 1961. Characteristics of agricultural innovators and other adopter categories. Katz, Elihu; And Others Studies of Innovation and of Communication to the Public. Studies in the Utilization of Behavioral, 62.

ROSTED, J. 2005. User-driven innovation: Results and recommendations. FORA 2005.

RUBACH, S., HOHOLM, T. & HÅKANSSON, H. 2017. Innovation networks or innovation within networks Accepted. The IMP Journal, 11, 178-206.

RUSIKE, J. Ã., TWOMLOW, S., FREEMAN, H. A. & HEINRICH, G. M. 2006. Does farmer participatory research matter for improved soil fertility technology development and dissemination in Southern Africa ? INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY 4(3), 4, 176-192.

SAITO, K. A., MEKONNEN, H. & SPURLING, D. 1994. Raising the productivity of women farmers in Sub-Saharan Africa, World Bank Discussion Paper, World Bank Publications.

SIMS, B. & KIENZLE, J. 2015. Mechanization of Conservation Agriculture for Smallholders: Issues and Options for Sustainable Intensification. Environments, 2, 139-166.

SIMS, B. G. & KIENZLE, J. 2006. Farm power and mechanization for small farms in sub-Saharan Africa. Agricultural and Food Engineering Technical Report (FAO).

SONTAKKI, B. S. & SUBASH, S. 2017. Farmer Innovation System: Rethinking the Way We Look at Farmer Innovations1. Agriculture Under Climate Change: Threats, Strategies and Policies, 383-391.

SUDA, C. A. 1996. Household Labor Use and Changes in Gender Roles on Small Farms in Ndhiwa Division, Western Kenya: The Challenge of Comparing the Contributions of Different

Workers. Arlington, VA Winrock International Inst. of Agricultural Development.

SUMBERG, J. 2005. Systems of innovation theory and the changing architecture of agricultural research in Africa. Food Policy, 30, 21-41.

TAMBO, J. A. & WÜNSCHER, T. 2015. Identification and prioritization of farmers' innovations in northern Ghana. Renewable Agriculture and Food Systems, 30, 537-549.

TAMBO, J. A. & WÜNSCHER, T. 2017. Building farmers' capacity for innovation generation: Insights from rural Ghana. Renewable Agriculture and Food Systems, 1-15.

TIETZE, F., PIEPER, T. & HERSTATT, C. 2015. To own or not to own: How ownership impacts user innovation–An empirical study. Technovation, 38, 50-63.

WELT HUNGER HILFE, IFPRI & CONCERN WORLD WIDE 2016. Global hunger index, getting to zero hunger.

WETTASINHA, C., DIOP, J.-M., VELDHUIZEN, L. V., WATERS-BAYER, A. & DOUTHWAITE, B. Undated. Small-scale farmers' perspectives on what enhances capacity to innovate.

11. PUBLICATIONS, CONFERENCES, TEACHING, PERSONAL ACHIEVEMENTS

11.1 Publications

- <u>*Co-Author:*</u> "*Smallholder Farmers and Climate Smart Agriculture: Technology and Labor-Productivity Constraints amongst Women Smallholders in Malawi"* published by the Gender, Technology and Development Journal, 20(2) 1–32©2016 Asian Institute of Technology, SAGE Publications. and number of citations
- <u>*Main Contributor:*</u> *"Supporting Women Farmers in a Changing Climate: Five Policy Lessons",* published by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) Policy Brief 10.

11.2 Conferences Attended

- Swaziland common bean network: presented the PhD research.
- Attended ceremony in Seattle, USA, as winner of BMGF call for proposals.
- Attended annual conference in Kenya for training on implementation of the WEAI index.
- Presented the PhD research in Cameroon, Benin and Ivory Coast during GIZ conferences as the research was selected as a success story on initiatives that are closing the gender gap.
- Facilitated the GIZ gender mainstreaming workshop in 2016
- Member of the Climate Smart Africa Alliance 2016-2018
- Supported the CSA profiling of stakeholders in Malawi 2016-2017

11.3 Teaching Experience during PhD studies

- Special speaker at the NUIG CCAFS M.Sc. students class based on PhD experience
- Conducted LUANAR Agri-engineering exchange visit with Malawian 3rd year students.
- Mentored recipients of AWARD program for women's entrepreneurship (1-year placement) during PhD research period.
- Mentored M.Sc. students doing their 6-month research in Malawi through PhD project.
- Supported PhD colleagues to conduct their research in Malawi using PhD research areas as entry points.

11.4 Project Resources Sourced from Funders and Private Sector

- Women Innovator groups gave their time and energy and farm land over two years. Without them, this research would have never been conducted.
- Bill and Melinda Gates phase I funding covered the first half of this PhD research from 2013-2015. GIZ GIAE phase II funding covered the second half of this PhD research from 2016-2017 as well as the production of tools and the impact assessment conducted in 2019. Care International funding covered the third year of this PhD research in 2016-2017.
- The PhD researcher identified relevant companies and partnered with Makerbot Industries who donated two 3D printers in 2014. Dream box, another private sector partner, donated 3D CAD software and provided technical backstopping during the tool design process.
- Concern Worldwide offered entry points where participants were identified from in the central region in phase I. In addition, they supported the research team with free transport and staff time during phase I (2013-2015). Catholic Relief Services offered entry points in the northern region.
- Lilongwe University of Natural Resources (LUANAR) offered staff time to test the feasibility of the technology concepts proposed during the research.
- Research volunteers, Ashenafi Tariku & Decolius Kalumo, offered their time and expertise to provide technical support on engineering aspects of this research.

11.5 Personal Accomplishments

- Secured scholarships from GIZ and BMGF to complete this PhD research from 2013 to 2019.
- The PhD researcher piloted this research in Malawi and with support from the PhD supervisor, established the 3D4AgDev as the NUIG base in Southern Africa. Other M.Sc. and PhD students also benefited from this for their own research from the NUIG & were posted within 3D4AgDev.
- This research was awarded the first place as winner of the Bill and Melinda Gates Foundation's call for applications for the accelerator program to close the gender gap in agriculture.
- Based on the presentations of this PhD research, the research was selected to represent GIZ Malawi in Cameroon, Benin and Ivory Coast during the annual conference three years in a row.
- The PhD researcher was recruited by an international NGO as senior technical advisor to manage a productivity enhancing participatory project in 2017 and has now received a promotion to Head of Component in 2020 to lead a renewable energy cooking component that promotes energy and labour saving technologies for household energy end-users in rural and semi-urban settings.