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Exploring the viability of re-introducing *Lablab purpureus* (L.) Sweet as a multifunctional legume in northern Tanzania

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Preface

This all started when I left my job as a research agronomist in Canada to enroll in the agroecology program at SLU. From there I developed the desire to do my thesis topic in Africa because I realized from studying agroecology that I knew little about the real issues facing smallholder farmers in the sub-Saharan region and I wanted to learn more by being on the ground. A professor I had while studying agronomy put me in touch with Neil Rowe Miller who is working on developing agriculture in Tanzania and he invited me to join them on a study they were working on.

People talk about the plight of smallholder farmers in Africa. They work to feed their families and sell whatever modest surplus they produce. It is a far cry from the large-scale industrial farming going on in many other areas of the world. It may be what they strive for though, that is to make farming more of a business and climb their way out of poverty. They may not realize it, but they farm closer to the principals that are taught in agroecology. They farm with few inputs, on small fields and practice intercropping. They trade locally, collect landrace seeds and have great respect for the land. These are the principles of agroecology because of their traditional systems. They farm the way it ought to be done everywhere and they may do so because they have few other choices. It creates a conflict between agricultural intensification and farming sustainably. Yes, they need help and there are many improvements to be made and we must find solutions that involve both agroecology and biotechnology, but perhaps they can learn from our mistakes by not going down the same path.

While the dream of studying in Africa came true, I learned so much more then I could have ever imagined. An important learning is that systemic-approaches to smallholder farmers' problems are needed. More research needs to focus on the social and ecological dimensions rather than just trying to maximize production.

This thesis is about one small crop, in one small area of Tanzania. It is about introducing locally adapted indigenous varieties back into the system that can potentially have many rewards for farmers. They do not need another study that is irrelevant to them. They need access to improved varieties that will fit in with their system, new knowledge to go along with the improved varieties and help with marketing and selling the product.

Christopher Forsythe
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Thank you to all my agroecology classmates and teachers for the inspiration to believe anything is possible. You reaffirmed to me that there are actually people in this world who can 'talk-the-talk' *and* 'walk-the-walk'.

Finally, I want to express appreciation to all the farmers who participated in the interviews. You had nothing to gain but you helped anyway and asked for nothing in return except help marketing your lablab. For that, I wish I could help you more.

Abstract

Smallholder farmers in northern Tanzania rely heavily on one cropping system of continuous intercropped maize with common bean; however, the system suffers rapidly-declining yields because of increasingly frequent droughts, poor soil fertility and no crop rotations. One way to diversify the farming system is by re-introducing a locally adapted, now 'forgotten' indigenous legume species called *Lablab purpureus* (L.) Sweet. Lablab improves food security because it provides multiple valuable benefits to farmers. Lablab is a nutritious food source for humans and livestock, generates income, reduces soil erosion, improves soil quality and is extremely drought resistant. However, widespread adoption by farmers is constrained by socio-ecological factors such as poor access to improved cultivars, extreme attractiveness to damaging insects, poor marketing channels, high transportation costs, perceived poor human palatability and lack of production and marketing knowledge.

This study used 30 interviews with a group of current smallholder lablab farmers in the region to determine if lablab is a viable and multifunctional crop for their livelihoods. The objective of the interviews was to learn more about farmers' uses of lablab and their traditional knowledge of lablab production in the hopes that barriers can be identified, and solutions recommended. Included in the thesis was a replicated field trial where several different locally-sourced indigenous lablab accessions were tested either sole cropped or intercropped with maize to determine if genetic insect resistance is available among them.

The farmers stated that they use lablab for many different functions, including income generation, human food, livestock fodder and soil improvements. They view lablab as highly important to their bottom line when the price is decent since it is more valuable than maize and common bean. They ranked economic reasons number one for both motivation and constraints for growing lablab. This highlights the shift towards using the crop primarily for income generation rather than for food consumption. The farmers stated they are constrained to grow lablab by poor marketability and often low grain prices, showing that the market needs to expand locally, and product transportation costs decrease to be viable. The insect relative abundance field experiment revealed some lablab accessions with significantly lower insect infestation compared to other accessions and commercial lablab varieties. This indicates the potential for insect resistant strains among the genetically diverse species. Another interesting finding was that intercropping lablab with maize can significantly lower the abundance of certain insect pest species.

The results of the insect study will hopefully be used towards developing and making available to farmers improved lablab accessions which will potentially reduce insecticide usage. The information gathered from the social science study will hopefully contribute towards reducing the barriers for adoption by smallholder farmers of a potentially important crop to improve their livelihoods and their food security.

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List of acronyms and abbreviations

CFGB	Canadian Foodgrains Bank non-governmental organization
cv.	cultivated variety
DAP	days after planting
ECHO	ECHO non-governmental organization based in the United States
FAO	Food and Agriculture Organization
GDP	gross domestic product
ha	hectare
i.e.	that is
IPM	integrated pest management
m.a.s.l.	meters above sea level
m	metre
mm	millimetre
n/a	not available
N	nitrogen
NGO	non-governmental organization
SARI	Selian Agriculture Research Institute
Subsp.	subspecies
TSh	Tanzanian shilling
USD	United States dollar
UNIANOVA	univariate analysis of variance

1. Introduction

A crucial challenge the world faces today is to increase food production for a growing population while increasing biodiversity and protecting the natural environment (Francis et al., 2008). These challenges, mainly directed at the industrial agricultural industry, are being reported on more frequently in the mainstream media today. For example, in January 2019, an article written by the journalist Fiona Harvey in The Guardian newspaper, was headlined: "Can we ditch intensive farming – and still feed the world?" This is a big question and I believe we can, but it will take systemic changes to the entire food system. Reporting of this kind are needed to help drive the changes that are necessary to overcome the challenges presented by these complex problems.

The agricultural technologies developed as a result of the Green Revolution have increased food production dramatically in some parts of the world, including Asia and South America but the same technologies bypassed smallholder farmers in Africa (Foyer, 2016; Tadele and Assefa, 2012). Aside from some technologies being introduced to improve certain crop varieties, smallholder farmers have not benefited from Green Revolution technologies largely due to socio-economic constraints (Huang et al., 2002). Technologies more suited to smallholder farmers, because they lack capital investment include: conservation agriculture (no-till farming), climate-smart agriculture, crop rotations, integrated pest management, pre-and post-harvest handling, natural resource management and improvements to the way food moves through the chain towards the customer (Huang et al., 2002). These alternative technologies and market chain improvements will have a greater impact on food security for smallholder farmers compared to modern conventional technologies because they are actually attainable.

Tanzania has seen "rapid" growth in the economic and agricultural sectors in the last decade, but poverty and malnutrition have not decreased at the same rate (Pauw and Thurlow, 2011). Malnutrition and poverty rate decreases have stagnated in Tanzania due to rapid population growth, off-setting any gains (World Bank, 2018). In Tanzania, 28% of people live below the poverty line and one in three Tanzanians are undernourished (CIAT; World Bank, 2017). Growth in the agricultural sector has mainly come from large farms producing non-food crops in a few select areas of the country whereas food crop and livestock production have decreased (Pauw and Thurlow, 2011). Pauw and Thurlow, (2011) contend this shows a disconnect between overall agricultural growth and improved nutrition outcomes. Smallholder farmers are left to produce most of the nation's food since they produce 70% of all food in Tanzania (CIAT; World Bank, 2017). Most analysts agree that the way out of poverty and towards meaningful national prosperity is through agricultural growth in food crops (White and Killick, 2001; World Bank, 2018) therefore, most of the burden falls upon the smallholder farmers of Tanzania.

Tanzania possesses vast areas of rich agricultural land but it remains one of the poorest countries in Africa and among the lowest in average agricultural production in sub-Saharan Africa (New Agriculturalist, 2003). Despite this, the country is relatively self-sufficient by supplying over 90% of its own food and producing all of its staples (including maize and beans) (FAO, 2017). However, in recent years the country has changed from a net exporter of agricultural products to a net importer (IFAD, 2017).

Foyer (2016) argues a “second Green Revolution” is now needed which includes increased production of ‘underutilized’ crops such as indigenous legumes because they can provide economic sustainability and thus improve food security. Leguminous plants are the second most important plant behind grasses for worldwide human food production and represent a promising supply of food into the future (National Research Council, 1979; Bhat and Karim, 2009). The importance of legumes is well documented. According to Batiano et al. (2011) they provide nutrition for humans and livestock. Secondly, they can help fight poverty because farm households gain income by selling the grain, leaves and fibre (Batiano et al., 2011). Lastly, they fix nitrogen, thus improving soil nutrients and subsequent crop yields.

Current Tanzanian farming systems include only a handful of different legume species and the vast majority of production includes only one kind, common bean (*Phaseolus vulgaris*) (Ronner and Giller, 2013). Furthermore, legumes grown in Africa are facing stagnating yield gains due to poor soil fertility, drought, pests and diseases (Batiano et al., 2011). The rest of the legumes are relatively underutilized and under-studied but have tremendous upside (Tropical legumes 2002). These ‘forgotten crops’ often have regional importance but they have been neglected by researchers because they lack economic and export value (Tadele and Assefa, 2012). They often serve an important local need by filling ecological niches; for example, they provide nutritious food in times of drought due to their inherent drought tolerance traits (Maass et al., 2010).

Ways to diversify the system need to be explored and expanded upon. One forgotten legume crop called lablab (*Lablab purpereus* (L.) Sweet) can help improve food security for Tanzanian smallholder farmers because of its multifunctional uses (National Research Council, 1979). Researchers and agricultural technical advisors are working on developing and making available to farmers some improved cultivars of lablab. They have also identified lablab as a potential ‘best-bet’ leguminous cover crop for practices such as conservation agriculture (Owenya et al., 2011).

An important threat to the widespread adoption of lablab is its extraordinary susceptibility to insect damage (Njarui, et al., 2004), which causes major economic losses. Many other challenges exist for its widespread adoption, such as poor marketability for one, but work needs to be done to try to determine if there are any genetic sources of resistance to insect pests among lablab accessions. Furthermore, a picture of the constraints and challenges, including knowing the socio-economic implications of growing lablab, is not possible without learning the farmers’ perceptions of the problems associated with its production and learning about their current management practices, which, for the most part, has not been explored.

1.1 Aim and research questions

The crop lablab is viewed as having many present and potential benefits to smallholder farmers for its adaptability to adverse conditions as well as its multi-uses (Maas et al., 2010). Information on the crop and its connection to farmers in East Africa is scarce due to its 'neglected' status (Maas et al., 2010). Additionally, the displacement and resulting reduction in production of lablab in favour of common bean (Robertson, 1997) have caused erosion of indigenous knowledge of agronomic practices for growing the crop (Miller et al., 2018). It is the aim of this thesis to investigate current lablab production and marketing habits by smallholder farmers in northern Tanzania as a means to help increase lablab knowledge and ultimately more production in the region. The factors that affect whether or not widespread adoption of these beneficial crops occurs are complex and it is necessary to look beyond just ecological factors. To find out what farmers are doing with regards to lablab will be accomplished by interviewing a group of progressive farmers within the study region.

A second aim will be to evaluate insect presence on of different lablab accessions. An accession can be defined as a group of related plant material from one species that have been collected at one specific time and location (OPGC, 2019). A group of lablab accessions, along with some commercial cultivars, totaling 21 different types, will be field tested to determine if genetic variations are present. The results of this study will be used to help identify possible insect-resistant germplasm that are suited to local environments, thereby enhancing lablab production and food security in the region.

The main research question for the thesis is: *Do a group of farmers in the northern Tanzania region perceive lablab as a viable and multifunctional crop to help diversify their farming systems?* (Both *viable* and *multifunctional* are defined below for determining this question.)

The following five specific research questions have been developed to help guide data collection and analysis:

1. What are current experiences and expectations of a group of farmers with growing, using and selling lablab in northern Tanzania?

2. Do the farmers perceive lablab as an important crop for their livelihood and a beneficial component of their farming system?

3. Which are the major insect species causing damage to lablab in Tanzanian farming systems and do they prevent production?

4. What are the strategies that farmers use to control insect pests?

5. Are there genetic variations among lablab accessions in their susceptibility to identified major insect pests? This is achieved by determining the insect infestation levels in both sole cropped and intercropped lablab with maize.

1.2 Definition of multifunctional and viable crop

The criteria for answering the main research question are given here for the purpose of determining lablab multifunctionality and viability in the present study:

Multifunctional crop – Food and forage belonging to the same function by the provision of harvestable products. Additional functions include promoting soil health by adding nitrogen through symbiosis with nitrogen-fixing bacteria and adding biomass through decomposing roots and above-ground mulch. Further functions include promoting beneficial organisms such as pollinating or pest-reducing insects and preventing soil erosion if the crop enhances the ground cover.

Viable crop – Ability to adapt to the agro-ecosystem of the studied farming system; ability to tolerate and overcome pest damages or other abiotic or biotic constraints; having a socioeconomic value for the farmers (such as green manure for soil improvement, animal feed or human food source as well as cash income generation).

1.3 Outline

The previous sections contained a brief introduction followed by the aim and research questions of the thesis. The next sections contain:

1. A general background through literature review of Tanzanian agriculture and the relevant topics of the legume lablab and the insects that attack it.
2. The conceptual framework used in the thesis, called the ‘socio-ecological niche’.
3. The methodology used for the structured interviews and the insect infestation level trial among different lablab accessions.
4. The main findings relevant to the research questions.
5. A discussion about the findings followed by a conclusion and recommendations section.

2. Background information

2.1 Agroecology and issues in the global food system

One definition of agroecology is “the integrative study of the ecology of the entire food system, encompassing ecological, economic and social dimensions” (Francis et al., 2003, p. 100). Another more specific definition of agroecology is “the study of the interactions between plants, animals, humans and the environment within agricultural systems’’ (Dalgaard, Hutchings and Porter, 2003, p. 42). Agroecology is therefore interdisciplinary. The key message is that the production of food right from the farm level to the consumer is a whole food system and all its component parts are connected. One part affects another.

The end goal of the science of agroecology is to transform the entire system by changing agriculture and the food supply to a more ecological, economically-sound and socially-just industry (Gliessman, 2015). A pioneer in agroecology, Gliessman (2015), argues that our current global food system is not sustainable in these three areas. Agricultural science is not enough to change an entire food system. For change of this magnitude to happen, a social movement is needed. It is being promoted to help because social change needs all actors involved and most importantly must have consumers, farmers, researchers and policy makers working together. Food networks need to be formed and all levels of the food system need to be linked (Gliessman, 2015). At the farm level, agroecological farming systems recognize that farm-site specifics are related to the socio-economic position of the farmer and the farm family.

The principles of agroecology are based on making the farming system more resilient. An agro-ecosystem is where the natural ecosystem is altered by agricultural operations caused by the needs of humans. The agro-ecosystem can be fragile due to a lack of biodiversity leading to many problems such as disease and pest outbreaks. Diversified cropping systems are more resilient than monocultures because these types of systems try to mimic natural ecological processes with practices such as intercropping, agroforestry and ecological diversification (Altieri, 2005). To make the system more resistant to these problems, planting many species (i.e. polyculture) and different varieties can provide "insurance" against negative environmental, social and economic shocks (Altieri, 2005). One way to diversify is to add indigenous legume species to a simplified cropping system that is based on only one or two commonly used crops.

2.2 Tanzania

2.2.1 Agricultural situation in Tanzania

The agricultural sector in Tanzania is extremely important to its overall economy, contributing to 31% to the GDP in 2015 (compared to 17% in the rest of sub-Saharan Africa) (CIAT; World Bank, 2017). Agriculture employs about 67% of the active population and continues to drive the economy (FAO, 2017). Agriculture remains predominantly smallholder (20 ha or less) at 91% of farms comprising over 14 million ha and over 35% of total agricultural land (permanent meadows and pasture plus cultivated land) with an average farm size ranging between 0.2 and 3 ha (CIAT; World Bank, 2017). Females make up 20% of the total number of landholders (CIAT; World Bank, 2017).

Growth in agriculture will have the most impact of all sectors towards improving the economy and lifting the country out of poverty (CIAT; World Bank, 2017).
Growth in agriculture has risen 6 to 7% in recent years (FAO, 2017) but larger-scale farmers have mainly driven this growth and furthermore, growth is limited to cash crops, such as flowers, grown in only a few regions in the country (Pauw and James, 2010). The authors argue that overall agricultural growth and rapid economic growth in Tanzania has not translated to improved human nutrition because there has been slow growth in livestock and human food production. One of the four priority areas in the FAO's

Country Planning Framework for 2019 in Tanzania is “increasing productivity and engaging smallholder farmers and traders in marketing and commercialization” (FAO, 2017). On the bright side, markets for export products are opening up especially for livestock and crops with “high demand and elasticity” (Arce and Caballero, 2015).

The effects of climate change make production even more challenging with an over-dependency on rainfall and degradation of natural resources that are being degraded. It is estimated that in Tanzania, climate change costs the agricultural industry $200 million USD each year (FAO, 2017). Other socio-economic barriers include lack of financial services, limited processing capacity and technology (New Agriculturalist, 2003). The government is pressing for the private sector to solve some of these problems (including supply inputs, credit, marketing and information) because government has historically been incapable of doing so due to lack of experience and resources (New Agriculturalist, 2003).

2.2.2 Tanzanian farming system

The main food crops produced in Tanzania are maize, dry beans, rice, sunflower, cassava, sorghum, groundnuts, sweet potato and coconuts, while major cash crops include coffee, tea, pyrethrum, tobacco, cashew and sisal (CIAT; World Bank, 2017). The largest crop is maize followed by common bean and rice with a total national harvested area of 24 %, 7% and 7% respectively. Common bean accounts for at least 80% of total pulses production in Tanzania (Lewis et al., 2008). About 40% of households raise livestock. The main imported products are soybeans, wheat and palm oil (FAO, 2017). The main export products are sisal, cloves, coffee, tobacco, cashew nuts, cotton, sesame and tea (FAO, 2019).

The main activity of smallholder farmers in warm arid and semi-arid tropics of northern Tanzania is maize/legume crop production, often including livestock integration (agro-pastoral) (Arce and Caballero, 2015). Crops are fertilized with dung; livestock are fed with residues. The type of crops planted by farmers is highly influenced by the environment (soil quality, water accessibility, pest resistance), the resources needed (fertilizer, manure, seeds, inputs, machinery) and economics (markets, seed prices) (Greig, 2009).

Smallholder farmers in Tanzania have poor access to modern technologies, external inputs and machinery and as a result, labour is intensive (Arce and Caballero, 2015). Other problems include low value addition of products due to high electricity costs, expensive transportation for products – due in part to isolation of rural communities with poor access to infrastructure and poor marketing opportunities (FAO, 2017). Agricultural inputs are available to small-holder farmers but locally the suppliers are not able to advise farmers due to lack of knowledge (Ronner and Giller, 2013). Weak farmer organizations resulting in poor relationships with input supply firms bring about additional constraints to use of inputs (Ronner and Giller, 2013). Due to these constraints, the potential of food production by crops and livestock has not been met in the country.

Overpopulation and changes in market demands cause changes to the agro-ecosystem. As the population increases at a high rate (the national growth rate in Tanzania was 2.8% in 2001) it results in less farmland available for each household. Therefore, the need either to intensify production or find new land results in a loss of biodiversity and land degradation. As markets change, the cropping system also changes. An example of this trend is the Arumeru district in the Arusha Region where farmers are growing more crops generating quick income such as cabbage and potatoes for the local market and flowers for export, thus displacing traditional crops (Ngailo et al., 2003). Land scarcity forces farmers to practice intercropping, with all needed crops growing in the same field at the same time. On the other hand, many soil conservation and land management techniques have been introduced to farmers, such as conservation agriculture and contour bunds on sloping land to reduce soil erosion. However, long-term adoption is often low (Ngailo 2003).

2.2.3 Access of small farmers to domestic and export markets

Market opportunities are expanding in Tanzania due to changes in government policies towards liberalizing international markets, specifically by removing tariffs on agricultural produce between Tanzania, Uganda and Kenya (Jones et al., 2002). This is a shift from an older policy of national food security first by feeding the urban areas (Jones et al., 2002). On top of this, the Food and Agriculture Organization (FAO) and other non-governmental organizations (NGOs) are helping small-scale farmers – who make up the majority of the poor in the country – by regarding the agricultural sector as a very important key to future poverty reduction and food security in Tanzania (FAO, 2017). In order for small-scale farmers not to be left out of these recent trade policies they need a competitive advantage. The small-scale farmers need more access to organized marketing, distribution and post-harvest storage, market information and channels, technologies and cooperative-forming training to access lower transaction costs (Jones et al., 2002). Growth in this sector will promote overall economic growth for a country (Jones et al., 2002).

According to Jones et al. (2002) conventional marketing channels for agricultural products have high distribution costs. Product is typically bulked and sold in villages to 'middle man' traders from local markets. Then the product is taken to larger centres and finally delivered to processors and exporters. So many changes of hand, combined with high transportation costs, results in a relatively small margins for farmers compared to final consumer prices while processors receive the largest share (Jones et al., 2002). Reasons for low farmer margins could be inefficiencies in the marketing chain, disproportionately high profits for traders and poor transportation and infrastructure (Jones et al., 2002).

To help fix these problems, stakeholders such as NGOs, private and public actors need to work more closely together. There is criticism that agricultural researchers and extension workers should do more to drive meaningful change by thinking beyond farm level productivity increases and begin to encourage strategic partnerships and work to affect policy in a positive manner (Jones et al., 2002). An example of such a partnership is to link an agricultural research institute directly with a not-for-profit marketing organization. The researchers thereby gain a partner who is more adept in marketing and business development.

2.3 *Lablab purpureus* (L.) Sweet

2.3.1 Lablab and its history

Lablab purpureus (L.) Sweet, also known as 'hyacinth bean' (synonyms: *Dolichos lablab*) is in the Fabaceae family and is often considered an indigenous African species (Maas et al., 2005; Robotham and Chapman, 2017). Vidigal et al. (2018) proclaim that East Africa is the "centre of hyacinth bean diversity origin". The name 'lablab' is speculated to be an Egyptian or Arabic word describing the dull rattling sound the seeds make inside a dry pod (Lablab.org, 2013). It is one of the most ancient cultivated crops (Foyer, 2016). The versatility of lablab is due to its being one of the most agro-morphologically and physiologically diverse domesticated legume species (Maass, 2016) having a large number of cultivars that are able to adapt and grow in a diverse number of agroecosystems (Haq et al., 2011).

To some, the crop is a regular source of food and protein to both animals and humans and to others it is much more than that. The Kikuyu tribe in Kenya have a long history of using lablab (termed 'najahe') and give the bean a "privileged category of their own" because of its traditional ceremonial importance (Robertson, 1997, p.262). The beans are strongly associated with women because they are the ones most often labouring to establish and harvest them. The female Kikuyu have a unique ceremonial, spiritual and nourishing usage for lablab beans (Robertson, 1997). Women were given the cooked beans to eat during all of their reproductive stages and especially post pregnancy because they are "…a special food, considered to be most nourishing" (Robertson, 1997, p.264). It has since been demonstrated that lablab grain is high in protein and can fight off malnutrition such as 'marasmus' and 'kwashiorkor' while possessing medicinal qualities, namely tryptophan (Sonali, 2015) and rich nutraceutical qualities (Bhat and Karim, 2009).

Colonial British rule in Kenya forced local Kikuyu lablab farmers to replace it with common bean intended for export to Europe and in the process eroded its familiarity with end-users, its genetic diversity and the farmers' knowledge of it (Maass, 2016). It was further eliminated from the landscape when the transition from subsistence farming to farming for cash income. Traditional crops such as lablab were often replaced with other legume species less adapted to their environment and consequently, more prone to adversity such as drought and pest attacks (Nahashon et al., 2016).

2.3.2 Current lablab production and constraints to adoption by farmers

Production of lablab in Africa is spread out in small pockets from Cameroon to Swaziland and Zimbabwe, through Sudan to Ethiopia and in East Africa including Uganda, Kenya and Tanzania (Murphy and Colucci, 1999). Production and demand of lablab in Kenya and Tanzania has decreased in the last 80-90 years. Evidence for this reduction has come from the Amumeru district in Tanzania where farmers reported approximately 10% of land was used for lablab in the 1930s and decreased to negligible levels in the 2000s (Ngailo et al., 2003).

Most production of lablab in northern Tanzania is for export as a cash crop to meet demand in Kenya from the Kukuyu communities (Ngailo et al., 2003). However, the exact amount of lablab being produced in Tanzania is unknown due to informal, undocumented trade and is estimated to be only 20,000 ha with 8,000 tons of grain produced with little domestic Tanzanian demand (Miller et al., 2019 (unpublished)). Market surveys by Ngailo et al. (2003) discovered that the demand for Tanzanian lablab has decreased due to changing eating habits of farmers as they are no longer relying on lablab as a steady food source. Another possible reason for lower production in Tanzania in recent times is that the lablab market is largely tied to the export price to Kenya and when it becomes saturated – due relatively low demand – the price drops significantly.

Reasons for low production come from consumers, processors and farmers. They include lablab's often viny nature resulting in more labour needed for harvest, low yielding potential, long cooking time of seeds and poor palatability of black seeds, pods and leaves. Recognizing these constraints, Grotelüschen (2014), did work in Kenya on choosing more palatable accessions that are coupled with good agronomic potential and identified two promising cultivars for further research. Other reasons for poor production are grain yield losses by insect pests and diseases such as yellow mosaic virus (Prasad et al., 2015). Additional reasons for low adoption in Tanzania are poor access to locally adapted seed, and a lack of good extension services.

2.3.3 Genetic diversity

The genetic diversity of lablab is high with over 3000 lablab accessions collected Worldwide (Maass, 2016). Maass et al. (2010) reported that the botanist Bernard Verdcourt found undomesticated, wild lablab in several African countries with both wild types and domesticated landraces having diverse genetic differences. This suggests that the continent holds great genetic diversity and future breeding sources. In Africa, the most genetic diversity occurs in Kenya and Ethiopia each having 403 and 223 reported accessions respectively and the rest of the countries in sub-Saharan Africa collectively having only 67 reported accessions (Maass et al., 2010). Pengelly and Maass (2001) developed a core collection of accessions intended to make available a diverse set with agro-morphological variation to different geographic regions. East African accessions collected more recently were found to differ from the core collection, meaning there is a potential for finding genetically distinct accessions suitable to the region (Maass et al., 2010).

Only a small handful of cultivars are commercially available, and they are often not adapted to the local environment. Most lablab varieties are longer-maturing than other grain legumes, such as common bean, which is a negative quality in the eyes of many farmers who prefer shorter-maturing varieties (Grotelüschen, 2014). The majority of current research on lablab in Africa centres on just one variety cv. Rongai for its agronomic attributes as an intercrop with cereals, for soil-improving qualities as a cover crop and for uses as a forage crop for livestock fodder (Maass et al., 2010). In a small number of cases, however, lablab research has been participatory in nature by working with farmers to find out how acceptable it is and what are the main uses (for example Manyawu et al., 2004; Ngalio et al., 2003). This kind of research is important for farmers to regain knowledge and become more familiar with the 'lost crop'. Research on lablab in Africa as a food crop requiring solutions for its poor marketing channels and perceived palatability issues is severely lacking.

Improved, shorter-maturing commercially available cultivars are available in India and in Bangladesh but not in Africa. In Bangladesh, five varieties have been listed as 'superior' for seed and vegetable use, which has led to an increase in production of 60% across 23 districts from 2004 to 2013 (Haq et al., 2016). In one district in Bangladesh called Pabna district, lablab production is "booming" and has doubled over this period. The district has become a centre of excellence for successful lablab marketing, making green pods and beans available from farmers who transport their produce to the local market. Numerous five-ton trucks depart daily transporting seed to other districts and there are even lablab exports by air destined to the UK and Middle East and by sea to many other countries (Haq et al., 2016).

2.3.4 Lablab growth habits

Lablab is an herbaceous legume that grows bushy and semi-erect and has a prostrate growth habit (Guretzki and Papenbrock, 2013). It is a long-lived annual or short-lived perennial (Murphy and Colucci, 1999; Njarui et al., 2004). In northern Tanzania the most commonly grown type is an annual for seed production and livestock forage where it is planted in the wet season and seeds are harvested four to six months later. Seeds vary from black, red, white and cream colours. Lablab flowers throughout the season and stays green long after the rains have stopped where other legume species have already dried up (Nahashon et al., 2016). Smallholder farmers generally establish both lablab and maize at the same time when intercropped, however some researchers advocate delaying lablab planting to reduce inter competition between lablab and maize (Mthembu, Everson and Everson, 2018). Lablab is slow- growing at first, but then grows vigorously choking out weeds, though it can climb and entangle the maize reducing the maize's capacity to grow (Mthembu, Everson and Everson, 2018).

Lablab is very adaptable to many conditions and can grow in arid, semi-arid, sub-tropical and humid regions and in many different soil types ranging from soil pH of 4.4 to 7.8. Lablab fixes nitrogen up to 170 kg/ha and leaves behind enriching soil organic matter from residues and roots (source needed perhaps Humphreys, 1995 or Schaffhausen, 1963)). Lablab is very drought tolerant. In Sudan, *Lablab niger* (hyacinth bean) is a hardy, drought resistant crop, cultivated as a cover, forage and food crop (Singh and van Emden, 1979). In a study of lablab accession growth in Kenya, Karachi (1997), found that during a drought season some higher yielding accessions did not show hastened flowering and therefore demonstrated that they did not even reach the critical stress limits.

Lablab is considered to be one of the most drought-tolerant legume species (Ewanisha and Singh, 2006). Lablab can still produce well with less than 650mm of water per year (Hendricksen and Minson 1985) making it a good fit for drought-prone regions (Guretzki and Papenbrock, 2013). However, the longer maturity time compared to common bean and cowpea (*Vigna unguiculata*) can make lablab prone to flowering stage abortion and thus low seed yields from drought due to variable rainfall over a long period (Whitbread et al., 2011). Therefore, Grotelüschen, (2014) suggested shorter-season varieties may be better for drought avoidance.

2.4 Multifunctional legumes and their sustainability

A multifunctional legume is a legume species that becomes more than just food and fiber; it provides ecological, economic and social benefits (Maass et al., 2010). One example is pigeon pea. Lablab is also considered to be one of these multifunctional crops by providing multiple uses for smallholder farm households (Maass et al., 2010; Foyer, 2016; Nandwa et al., 2011; Pengelly and Maass, 2001; National Research Council, 1979; Whitbread et al., 2011). Besides providing food to humans and a source of income as a cash crop, Nandwa et al. (2011), argue multifunctional legumes have many other uses: (1) they are nitrogen-fixing crops that can be sole cropped, intercropped or in rotation with other crops, 2) they are good green manure crops providing erosion control and adding organic matter to the soil, 3) they provide reduced moisture evaporation as a cover crop that works well in coffee and coconut plantations as well as fruit orchards, 4) they are a highly palatable source of fodder when grazed by cattle, sheep, goats and pigs. Specifically, lablab can be grazed after the grain is harvested and makes good hay and silage. These alternative uses must also be considered for importance to a system.

Single-purpose herbaceous legumes only meant for increasing soil fertility (green manure) are not practical for poor farmers due to land scarcity where staple food production is always needed (Rao and Mathuva, 2000). Other single-purpose high-yielding grain legumes, such as soybeans, have a high N harvest and remove net amounts of N from the soil rather than add to it (Vanluawe and Giller, 2006). This makes a multipurpose grain legume crop that adds soil N (high shoot and root biomass) while producing a reasonable amount of seed such as pigeon pea and lablab more attractive to small-scale farmers (Mugendi et al., 2011).

There are examples of how providing lablab to famers had sustainable effects on their farming system. The authors Dixon, Gulliver and Gibbon, (2001) suggest that when cash crops, such as grain legumes or oilseeds, are grown with maize, they act as dual-purpose cash and subsistence crops. When grain legumes are often worth as much as three times the price of maize, one could argue that they too can be a cash crop. Manyawu et al. (2004) conducted a four-year socio-economic study of introducing free seed of the multipurpose forage legumes lablab and *Macuna pruriens* to smallholder farmers in Zimbabwe to improve livestock production and soil fertility. The crops fit in well to an integrated crop-livestock system for their drought tolerance while providing fodder and seed to eat and sell. The farmers were happy with lablab's drought tolerance and the number of farmers who grew lablab increased over the period in one community by 20% and in another by 68% as they gained knowledge about how to grow it. Neighbour farmers to ones involved in the study also started to grow the crop and were termed 'adopters' and demand for the seed increased. The farmers in the project concluded that adopting lablab and *Macuna* into their system positively impacted their livelihoods by increasing the quality of feed for their cows and by saving money on N fertilizer. Lablab can also be more economically feasible when fed as a protein supplement to animals. In a study by Komwihangilo and Mlela (2012) goat farmers in Central Tanzania were provided with leaf-meals of lablab and economic analysis showed it was more profitable than using the conventional supplements of cotton seed cake.

2.5 Insect pests of legumes

Insect pests are one of the main limiting factors in grain legume yields in the tropics (Singh and van Emden, 1979). Pre- and post-harvest losses due to pests and diseases of legume crops in Africa are large and estimated to be between 30 to 40 per cent (Amani, 2004) but total crop loss can occur if plants are unprotected (Miller et al., 2018). The application of insecticides lessens yield loss dramatically. As an example, Singh and van Emden (1979) reported some dwarf short maturity pigeon pea varieties in Nigeria, achieved zero yield due to insect damage but when pesticides were applied, they commonly yielded over 1500 kg/ha.

As is the case for other legumes, lablab is a host for many insect pests that cause economic loss. Additionally, damage can occur at all stages of production, even in grain storage (Abate and Ampofo, 1996). To highlight its attractiveness to insects, lablab was often used in Africa as a pod borer (*Helicoverpa armigera)* trap crop, even when not in bloom, to protect cotton (Hardwick, 1965).

Abate and Ampofo (1996) grouped pests on legumes into five broad categories based on the plant parts they attack: seedlings, foliage, flowers, pods and harvested seeds. The most important pests of lablab grown in Tanzania have been identified as those that attack during the flowering and pod-forming periods (Miller et al., 2018). The main field pests that attack lablab include flower thrip (*Thysanoptera: Thripidae*), black bean aphid (*Aphis craccivora*), pod sucking bug (*Riptorus pedestris, Clavigralla tomentosicollis etc.*), flower or blister beetle (*Mylabris* subsp.), legume pod borer (*Helicoverpa armigera, Maruca vitrata etc.*) and bruchid (*Coleoptera*: *Bruchidae*) during grain storage.
Flower thrips damage the terminal leaf buds and later on the flowers, causing malformation and discoloration where abortion can occur (Abate and Ampofo, 1996). Nahashon et al. (2016) researched aphid damage on lablab in Kenya and found that aphids can cause low production. Pod sucking bugs attack tender pods and cause them to be shriveled and seeds to be misshapen or abort (Jackai and Daoust, 1986). Blister beetles are widely distributed in Eastern Africa; adults can ravage flowers and reduce pod set (Singh and van Emden, 1979; Abate and Ampofo, 1996). Legume pod and seed borers feed on and cause severe damage to tender shoots, flower buds, flowers and pods of all

sizes. They can dramatically reduce crop yields all across the sub-tropical areas. Yield losses in Tanzania of common bean due to pod borers can amount to 30% (Karel, 1985). The time of season and stage of plant growth can affect pod borer pressure that causes damage. Abate and Ampofo (1996) reported that the average number of *Helicoverpa armigera* eggs laid during the rainy season was 1226, and only 198 in the dry season and highest egg production by *Helicoverpa armigera* occured during peak flowering. Additionally, two to eight generations of *Helicoverpa armigera* per year are possible depending on biotic factors such as temperature and host plant presence (Sambathkumar et al., 2017).

Tolerant or resistant crop varieties to insects are important components of an Integrated Pest Management (IPM) strategy to reduce crop damage and insecticide usage. Tolerance can occur in the form of avoiding peak pest populations during the plant's vulnerable periods (e.g. flowering) by early-flowering or early-maturity. Information on genetic resistance to insects in lablab is limited however, there are cases of genetic resistance in lablab to pod borer. Field screening work done by Prasad et al. (2014) found variability in genetic accession resistance to pod borer. These results were similar to Naik and Patil (2009) when screening 68 germplasm accessions of lablab they found six that were resistant to pod borer *Adisura atkinsoni*, and all were early maturing types. Regupathy et al. (1970), found while working in India, low incidence of pod borer and lower yield loss in field bean (lablab) correlated with early relative maturity due to early unpalatable lignin formation. They also found that flower colour or seed coat did not affect pod borer incidence. In a separate crop, cowpea, Singh and van Emden (1979) reported some varieties were resistant to aphids (*Aphis craccivora*) but on the other hand they suggested that for many harmful insect pests, such as *Helicoverpa armigera*, no host resistance is available and chemical control is recommended (Naik and Patil, 2009; Singh and van Emden, 1979).

The health cost for farmers and the economic cost of spraying insecticides are high (Abate and Ampofo, 1996) and many Tanzanian farmers have to spray their lablab crops two to three times per season to have any sort of production (Miller et al., 2018). Farmers who participated in a study in South Africa reported that lablab was unsuitable on some occasions due to the prohibitive cost of pesticides after attacks by aphids during drought (Manyawu, 2004). Finding out farmers' indigenous knowledge and techniques on pest management and control strategies is helpful for developing low input management technologies they can easily adopt (Abate and Ampofo, 1996).

2.6 Intercropping legumes and cereals as a control strategy for insect pests

An effective strategy to reduce insect pests in legume cropping is intercropping (i.e. mixed-cropping or diverse polycultures) (Amoako-Atta et al., 1983; Perrin, 1976). The pest management strategies of peasant farmers and their traditional cropping system of intercropping maize with legumes can play an important role in insect pest control (Altieri et al., 1978). Intercropping of several species together in space and time can minimize crop loss from a pest attack because the risk is spread out (Perrin, 1976). The reasons are not fully understood but possible mechanisms for reduced insect incidence in polycultures include more natural enemies, increased shading and chemical interactions (Altieri et al., 1978). Abate and Ampofo (1996) reported that traditional systems that use small fields of common bean results in less insect damage compared to larger fields and that intercropping beans with other crops such as maize reduces damage of *Helicoverpa armigera* compared to sole bean crops. One hypothesis for lower herbivore insect populations in complex systems is that predators and parasites of pests are more effective than in sole crop systems (Altieri and Francis, 1978) possibly due to increased habitat for the beneficial insects. Therefore, intercropping can potentially reduce the frequency of insecticide applications needed (Singh and Ajeigbe, 2002).

However, there are conflicting studies with respect to how effective intercropping is for reducing insect damage. Otway, Hector and Lawton (2005) found that when host plants were in diverse polycultures, they experienced higher herbivore pressure by specialist insects since the host plant was less abundant and a 'negative dilution effect' occurred. Sharma (1998) reported that during field screening of cowpea for resistance to pod borer, resistance was reduced when cowpea was intercropped with maize and they attributed this to increased pod and peduncle length.

3. Conceptual framework

3.1 Legume-based technology

The benefits of diversifying a system with 'legume-based technology' are well researched (Vanlauwe and Giller, 2006) and can improve the livelihoods of smallholder farmers (Nandwa et al., 2011). Legume-based practices include using nitrogen-fixing legume trees, shrubs or herbaceous crops to improve soil nitrogen levels to increase production (Mugendi et al., 2011). However, there have been relatively low rates of legume technology adoption by smallholder farmers in sub-Saharan Africa (Friesen et al., 1996; Rowe and Giller, 2003; Ojiem et al., 2006). An example of utilizing legume technology is by growing short to medium-term legume cover crops, either in rotation or in relay with cereal food crops, or in fallow periods and allowing nutrients to be released into the soil (Rowe and Giller, 2003). Species used for this type of system may include: *Mucuna* subsp. or *Tephrosia vogelli or Canavalia ensiformis,* (Mugendi et al., 2011). Another example of legume technology is by growing multipurpose grain legumes that fix large amounts of nitrogen, such as pigeon pea, that provide additional value by supplying high-quality product to domestic and export niche markets (Jones et al., 2002). Adopting legume-based technologies such as including a legume green manure in a maize rotation has been shown to raise maize yields in the following season by as much as 384% (Friesen et al., 1996). Adding a grain legume into a maize system can be more profitable than sole maize by adding 32-49% more net income (Rao and Mathuva, 2000). Kimaro et al. (2016) reported in Kenya when lablab was added to maize in a conservation agricultural (CA) system it added 40% in yield. Conversely, a vigorous green manure legume, such as *Mucuna* intercropped with maize can significantly reduce maize yields depending on the competitive ability of the green manure crop (Friesen et al., 1996). The potential benefits of using a legume technology are demonstrated for smallholder farmers (Rowe and Giller, 2003; Vanlauwe and Giller, 2006) but there are many factors that influence adoption or non-adoption.

3.2 Socio-ecological niche concept for adoption of legume technologies

The previous sections explain what multifunctional legumes are and also describe how using legume-based practices can improve a system. This section provides conceptual framework to assess how legume technology may adapt and become adopted into a system. It provides support to the theory of this paper that, for successful re-introduction of a legume, many elements need to be addressed.

Whether adoption of a legume technology occurs or not on a specific farm is often due to many factors, such as the environment, socio-economics, the farmer's risk tolerance/aversion and the extension service (Ndove, et al., 2004). The framework is based on the understanding that a systems approach is needed since smallholder farms in sub-Saharan Africa are very complex and analysis of only one factor is not sufficient. Ojiem et al. (2006) propose the idea of a 'socio-ecological niche'. The concept acts as framework for increasing the rate of adoption by analysis of four main factors to differentiate a niche (see Figure 1): (1) Ecological factors such as rainfall, temperature and soil type; (2) Socio-cultural factors such as policy and regulations, education, advisory services, gender, values, preferences and labour allocation; (3) Economic factors taking into account off-farm income, land tenure, cash flow, capital, private or public investments, profitability and input and output markets; (4) Local ecological factors including weeds, pest types, soil moisture and soil fertility.

The four main factors work in hierarchy, and analysis through each factor in succession exposes "niche criterion" that must be met and solved within a system. An example of a niche criterion in a socio-cultural context is a farmer may face three constraints for adopting a legume technology: one is land scarcity, second is labour shortage and third is input shortages. The three constraints may act in isolation of each other, or in combination of two together, or all three combinations at the same time affecting each other. With identification of the constraints and the combinations in a complex system, work on solutions can begin. A solution for the situation of land scarcity caused by dwindling farm size could be improved by intercropping legumes and cereals therefore producing more with two different staple crops on the same area. Then an appropriate legume that grows well when intercropped can be chosen. Strategies to solve the other issues of labour and input scarcity can begin to be worked through. Perhaps the issue of labour shortage is rooted in gender roles where men typically don't take care of 'bean' production leaving the brunt of the work to women (Pircher et al., 2012). Breaking down these gender roles by empowering woman through women farmer community groups may have an impact on labour shortages. Access to inputs such as rock phosphate may be unattainable for most poor farmers so they may have to find alternatives in animal manure, compost or composted human waste. Solutions are not without major challenges but only once they have been identified may progress occur.

This niche concept is meant to allow researchers to look at more than just environmental factors when determining 'best-bet' legume technologies for a farming system (Nandwa et al., 2011). The outcome will mean potentially higher adoption rates by identifying the barriers to adoption and then solving them.

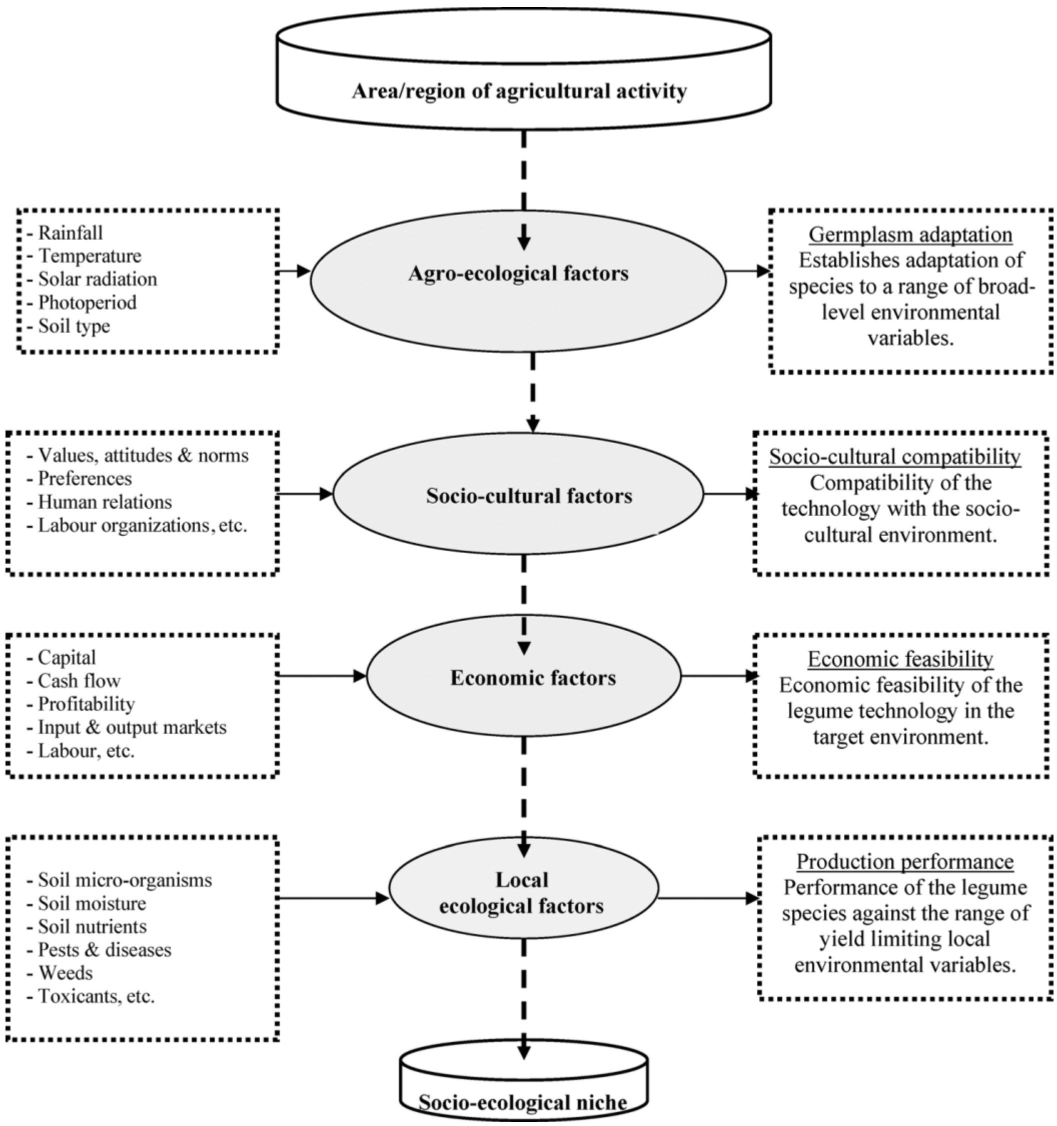

Figure 1 'Socio-economic niche' concept describing 4 hierarchical levels for providing framework of determining a suitable niche environment for a legume technology in a given area as presented in: Ojiem et al. (2006).

There are many examples of successful adoption of legume-based practices. For instance, participatory research by Kerr et al. (2007) in Malawi saw 3000 farmers testing legumes. They gained valuable knowledge on contribution by legumes to soil fertility and child nutrition leading to higher rates of adoption. Adoption of legumes was high with more families feeding legumes to their children compared to the 'non-adopter' legume control group. A 57% increase in farmers reported they buried legume green manure residues over a 5-year period from 2000-2005, especially female farmers. Farmers chose more edible legumes for intercropping compared to green manure only legume-based systems (for example *Mucuna pruriens*), for the reason that they could also sell or eat the grain produced. Farmers' personal values, motives and motivations are required to try different technologies, but this is often not enough; for instance, they may need financial incentives (Jones et al., 2002). This is a similar view to Caswell et al. (2002, p 5) on adoption of production practices research: "There is a distinct difference, however, between a producer who is unable to adopt versus one who is unwilling to adopt".

4. Methodology

This study is based on empirical data gathered through fieldwork in northern Tanzania during April to June 2018, as well as secondary data from peer-reviewed academic literature, reports and official documents. Fieldwork consisted of two interrelated phases. The first phase focused on qualitative and quantitative data collection by conducting structured and informal interviews with farmers and various actors in the field. The interviews were to explore the farmers' views of the situation involved with lablab growing, selling and consumption in northern Tanzania. The second phase involved gathering quantitative data with a lablab field trial. This study was used to determine if there is variation among accessions to insect pests both sole crop or intercrop. Altogether, the three different data sources will form a "triangulation" which is used as a method to support findings by using independent data sources to either agree or disagree with the main findings (Miles and Huberman, 1994).

4.1 Description of the six study locations and their respective regions

The study was carried out in six villages in three northeastern regions of Tanzania, namely: Kilimanjaro, Arusha and Dodoma, covering an area of 13,209 km$_2$, 37,576 km$_2$, and 41,311 km$_2$ respectively. The population densities of Kilimanjaro, Arusha and Dodoma are 124, 45 and 50 people per km$_2$ respectively. Much of the study area, except for the Arusha highlands, receives less than 1000 mm of rain per annum. All regions suffer from unreliable rainfall (either too little or excessive amounts), and drought especially in semi-arid areas such as Dodoma, where evapotranspiration is high (Sarwatt and Mollel, 2006). Field crops are generally planted in the long rains called 'masika' which occur in March to May. The soil type of the Arusha and Kiliminjaro regions are predominantly volcanic and have high agricultural potential while in Dodoma region, it has a mix of black vertisol and red soils (Sarwatt and Mollel, 2006).

In the Kilimanjaro region 26.7% of households produce only crops and 72.4% are involved in crop and livestock production (NSCA, 2007). In the lower elevation zone of the region, the main products are maize, beans, cotton, paddy and livestock rearing (NSCA, 2007). In the middle elevation zone, the main agricultural products produced are wheat, beans, maize and dairy (NSCA, 2007). In the upper highlands zone (1,500 m - 3000 m), coffee, bananas, maize, beans and dairy cattle are produced (NSCA, 2007).
In the Arusha region, 19% of farms are involved in crop production only and 66% were involved in both rearing livestock and producing crops (NSCA, 2012). The main products

are cereals, pulses, fruits and vegetables, nuts, roots and tubers. The cash crops are mainly cotton and tobacco (NSCA, 2012).
In the Dodoma region 72% of farms are involved with crop production and 26% involved with both crop and livestock production (NSCA, 2006). There were no purely pastoralists in the region according to the 2002/2003 censuses by the government (NSCA, 2006). Only annual crops are planted due to the extreme dry season. In order of importance, the annual crops produced are: cereals (maize was the most important of cereals with 74%), oilseeds, pulses, roots and tubers and fruits and vegetables.

Farmers came to do the interviews from the surrounding parts of each study location described in Table 1 and shown in map form in Figure 2. The six locations were: Mungushi, Elkushi, Karatu and Mang'ola located in the Arusha region, Kondoa located in the Dodoma region and Hedaru located in the Kilimanjaro region. The livelihood zone where each village lies in is listed in Table 1 as an alternative descriptor to agro-ecological zones (Perfect and Majule, 2010).

The farming systems at all six sites produced similar staples with different enterprises depending on the livelihood zone of each site. The majority of the farms can be described as mixed, consisting of both crop production and animal husbandry. Farms are still largely for subsistence. Anything that is produced and left over after family needs are met is sold. There are some crops grown specifically for cash and income is used to buy food, pay living expenses and pay for crop inputs, and labour. Increasingly, farmers are treating the farm enterprises like a business by producing more for income and less for food. Most farmers in the three study regions plant maize each year and use it as home consumption in the often-eaten dish called ugali. Maize is commonly intercropped with a legume, such as common bean, green gram (*Vigna radiate*), pigeon pea or lablab. After harvest the residue becomes communal grazing for livestock and this practice makes planting legumes, perennials or cover crops difficult.

Table 1 Description of the six study locations used in the structured interviews across northern Tanzania including the district, region, livelihood zone, faming system, elevation (m.a.s.l.), rainfall (mm/yr.) and mean annual temperature (°C).

Location	District	Region	Livelihood zone	Farming system	Elevation (m.a.s.l.)	Rainfall (mm/yr.)	Mean annual temperature (°C)
Mungushi	Arusha Rural	Arusha	LZ5 (Pastoral zone)	Pastoral, maize, legumes	1016	Bimodal, unreliable, 450-700	20
Elkushi (near Arusha city)	Arusha Rural	Arusha	LZ1 (Highlands zone)	Coffee, banana, maize, legumes	1300	Bimodal, 1250	19.2
Karatu	Karatu	Arusha	LZ5 (Pastoral zone)	Pastoral, maize, legumes	1650	Unimodal, unreliable, 905	19.2
Mang'ola	Karatu	Arusha	LZ5 (Pastoral zone)	Pastoral, maize, legumes	1080	Unimodal, unreliable, 693	22
Kondoa (Mjini)	Kondoa	Dodoma	LZ4 (Semi-arid zone)	Sorghum-livestock, maize legumes	1400	Unimodal, unreliable, 719	21.2
Hedaru	Same	Kilimanjaro	LZ5 (Pastoral zone)	Pastoral, maize, legumes	756	Unimodal, unreliable 605, long dry spells common	25.4

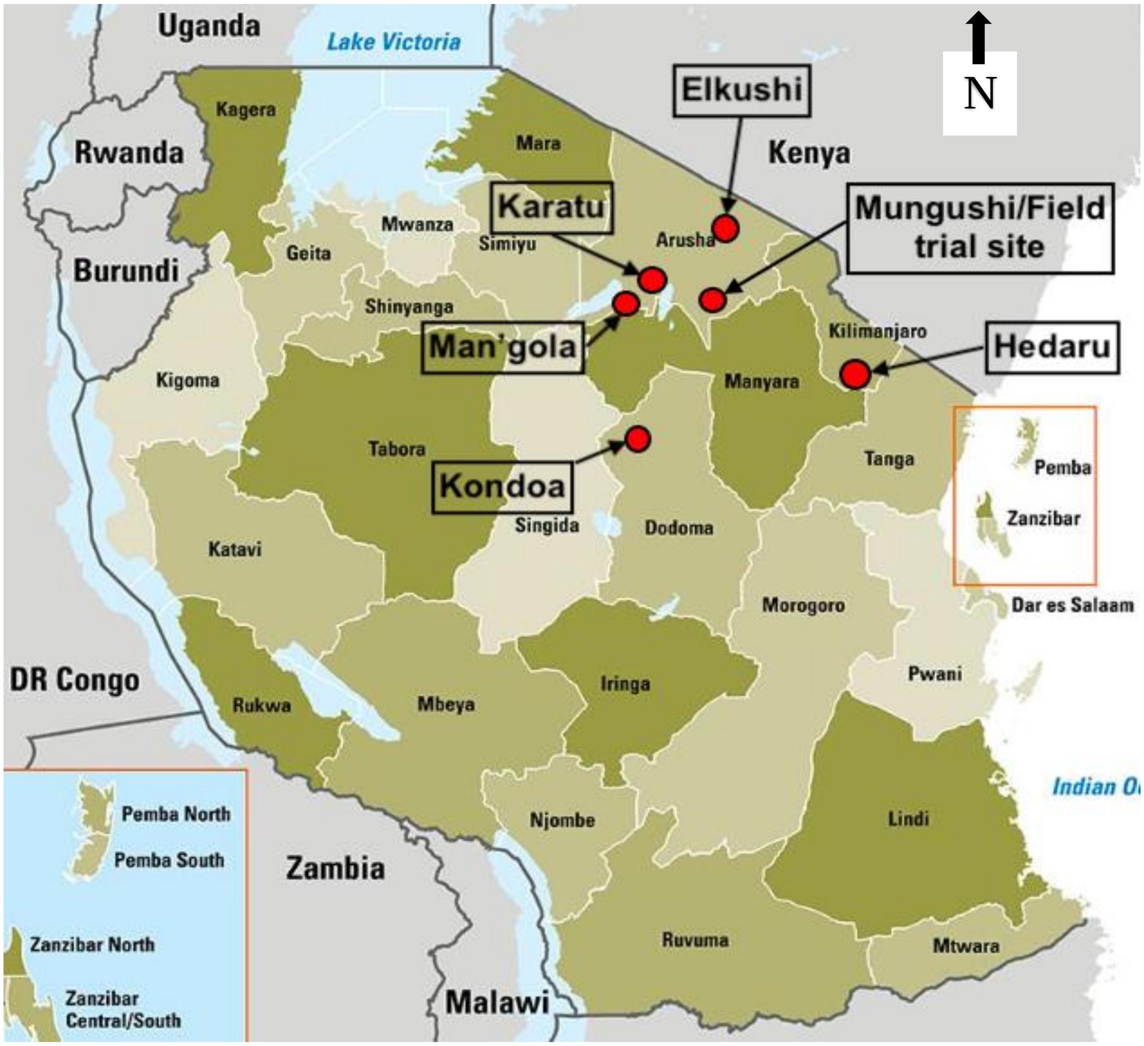

Figure 2 This map shows the six locations where structured interviews took place and one insect field trial site at Mungushi in northern Tanzania. Source: maps Tanzania.

4.2 Farmers' semi-structured interviews and informal interviews

4.2.1 Background and description of the study group

Researchers at Canadian Foodgrains Bank (CFGB) and Selian Agriculture Research Institute (SARI) located in Arusha, Tanzania established a group of 30 farmers across north-central Tanzania to participate in on-farm lablab accession performance trials. The different geographical locations allowed testing of accessions in different agro-ecological zones and elevations. Since this farmer group was already in place, it made sense to interview these farmers in their communities for the current study.

The sampling method used was a purposeful sampling strategy (Creswell, 2007). This approach involves determining ahead of time some criteria to distinguish participants from others so they can "…purposefully inform an understanding of the research problem and central phenomenon in the study" (Creswell, 2007, p. 125). In this case, the distinguishing factor was lablab-growing experience. These farmers could therefore provide an understanding of lablab production that non-lablab growers could not. Diversity in the sample was achieved by selecting six different geographic locations creating variation. A disadvantage of targeting this type of group was losing the random sampling effect, which could have been used to provide better estimates for farmers in the region as a whole. In the end it was deemed more advantageous to use the pre-existing on-farm trial group for this study.

4.2.2 Structured interviews and strategy

Information to gain insight into farmers' perceptions and management of lablab was collected by administering structured interviews. Additional interview goals were to determine the suitability of lablab in the existing farming systems and the farmers' preferences for crop selection. Farmers detailed their lablab production practices and where their knowledge came from. Additionally, they spoke of their seed sources, marketing procedures, major constraints and main reasons for growing lablab. Relevant household socio-economic data was collected for a holistic analysis. The interviews were made in person to provide a better understanding of the context or setting where farmers face problems (Creswell, 2007).

In total, 28 farmers in six districts across northern Tanzania were interviewed. At each district four to six interviews were conducted. The interviews lasted approximately 60 minutes each and took place in village centres or at the interviewee's home. The interviews contained 30 open-ended and closed questions and both quantitative and qualitative data was generated (Appendix 1).

Figure 3 A structured interview with a farmer in progress at Mang'ola, (Arusha region) Tanzania, May 2018. Photo: Chris Forsythe

The questions in the interview were developed in order to help answer the main research questions and specific sub-questions (Creswell, 2007). The questions were asked in English and then translated to the farmers in their local language (usually Kiswahili or Pare) by an ECHO intern translator. Some open-ended questions and visual aids (for example asking questions involving the farmer to answer by placing beans in boxes) were used to break the monotony of short answer and 'yes' or 'no' kinds (Bernard, 2006). Clarifying and probing type questions were occasionally asked by both the interviewer and the translator when the answer provided was unclear and more information was required. Responses were translated and transcribed either on paper or typed on a laptop. All interviews were audio recorded but poor recording equipment made it hard to properly hear conversations. The questionnaires were first developed in English then translated to Kiswahili and finally tested on farmers who were not part of the sample group. Changes were made accordingly.

4.2.3 Informal interviews

Spontaneous interviews were conducted while in the field with key informants. No pre-prepared interview guide was used as these interviews were opportunistic and not anticipated. These informal, open-ended question type conversations involved relevant actors who could provide additional insight and an alternate perspective to the problem. The goal was to speak to these actors and develop a dialogue to get whatever information from them that seemed relevant to the study. This allowed them to have some freedom to talk about what is important to them and provided flexibility to be able to ask follow-up questions (Bryman, 2012). Informants included a grain trader, a healthcare professional, a government extension officer and a conservation agriculture officer. Prior to each interview, interviewees were asked for their permission to be voice recorded and to use their input and pictures in the current study.

Figure 4 Informal interview with actors involved in lablab trade near Ngaramtoni market, Arusha Tanzania, May 2018. Photo: Chris Forsythe

4.2.4 Structured and informal interview analysis

All data from interviews were recorded onto a single spread sheet in Excel for reference. The coding approach used for the qualitative data was descriptive coding which summarizes a passage with a short phrase or a key word and developing a label (Miles, Huberman and Saldana, 2014). The labels or themes were put into categories that relate to each other and each similar category was counted and described, using text, figures and tables (Creswell and Creswell, 2018). Quantitative data were simply tabulated and calculated either as a percent response or number of responses, and charts or tables were used to display results. In order to reduce congestion with excess data, some decisions were made about what to decide what to include and what to omit. For the most part, only answers that were directly related to the research questions were selected for analysis (Miles and Huberman, 1994). To help organize which interview questions answer the specific research questions, each question was labeled to match with a research question (Miles, Huberman and Saldana, 2014). The last stage of data analysis was to interpret themes, find interrelations between them and look back to generate logical inferences. Notes and recordings from the informal conversations were synthesized and themes were developed to help add support to answering the thesis research questions.

4.2.5 Limitations, reliability and generalizability

The intent of qualitative research is not to generalize findings to people or places outside of the study (Creswell and Creswell, 2018). Therefore, the results in this study cannot be accurately extrapolated to reflect the situation outside of the study group for two reasons: Firstly, the study group chosen is not representative of all farmers in the region since it was not a random sample. They all had in common one thing and that was growing lablab. Other farmers may not have been lablab growers. Secondly, the findings must be used very cautiously to predict whether experiences of other lablab growers are similar to the study group since this group are considered very progressive and innovative, demonstrated by the fact that they are willing participants in on-farm trials of 'new' legume practices which carries a degree of risk.

As an interviewer, it is important to self-reflect and be transparent about the process (Creswell and Creswell, 2018). There were several limitations to generating reliable data in this study. Most limitations centre on the lack of experience by the interviewer and translator leading to situations where the interviewee is 'led-into' answers causing possible inaccuracies. Another limitation was that answers were often simply 'lost in translation'. Additional follow up or clarifying questions were difficult due to the language barrier and the time limitation for each interview.

4.3 Insect trial materials and methods

4.3.1 Study site

Infestation levels of thrips, pod borers, aphids and pod sucking bugs were evaluated at one site in northeast Tanzania (Figure 2). The site was located in the Arusha district near the small village of Mungushi, at the latitude of 3° 33' 15.372" S and longitude of 36° 51' 18.108" E approximately 35 kilometres south-east of Arusha city (see Figure 2). The site's elevation is approximately 1016 meters above sea level with bimodal and unreliable rainfall patterns accumulating 450-700 mm average rainfall yearly. The mean temperature is 20°C. The crops commonly grown in the area include maize, beans, green gram and lablab.

4.3.2 Weather conditions at study site during evaluation period

Temperature was not recorded at the study site, but rainfall was documented by the farmer who was maintaining the trial. The closest weather station was located at Mbuguni approximately 15 km NW of the Mungushi site.

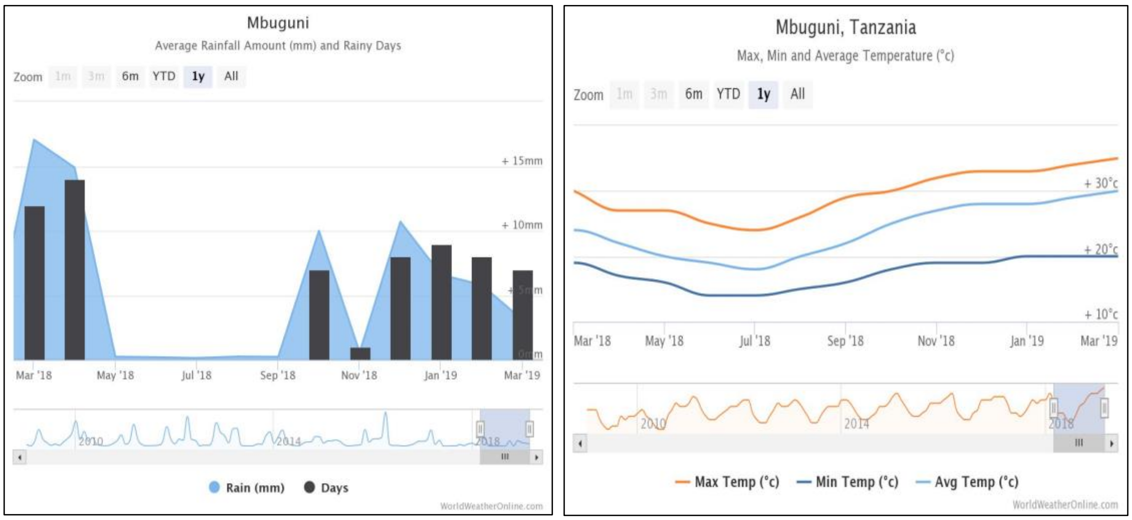

Figure 5 Rainfall and temperature data from Mbuguni, Tanzania (closest weather station to study site March to July 2018). Source: World weather online

The average high and low temperatures during the period of evaluation (from March to July 2018) were 26.4°C and 16.4°C, respectively. Rainfall at the site was not documented prior to planting on March 23 but it was sufficient for germination and development of a uniform and vigorous stand. After lablab planting, 193 mm of rain fell in April and 23 mm in fell May. No rain fell after May for the duration of the trial period.

4.3.3 Design and treatments

The field experiment evaluated 21 different lablab accessions including two commercial varieties as controls (cv. Rongai and cv. Highworth). The cultivars were selected from the core collection established by Pengelly and Maass (2001) plus seed from registered Kenyan varieties and Tanzanian and Kenyan farmers landraces. Farmer landraces for the present study were selected based on “best bet” accession performance from yield trials in 2016 and 2017 located in Tanzania conducted by the work by researchers at CFGB and SARI (Miller et al., 2018). Accession yield, relative maturity, days to 50% flowering, proneness to insect attack, drought resilience and seed coat colour (based on consumer preferences where the Kenyan market prefers black seed), were all used as selection criteria. The goal was to measure differences among accessions for insect resistance and intercropping with maize versus sole cropping.

The experiment was designed as a modified split-plot with plots replicated three times (Figure 7). An equal number of lablab or intercrop lablab-maize plots were randomized, however sole crop and intercrop plots were placed in separate rows. Each block contained 8 rows by 6 columns with plot dimensions of 6 m x 5.4 m giving total block width of

42.4 m by 34.5 m in length. There was a 1.4 m wide alley between plots at the plot ends and there was a 2 m wide alley separating blocks. Lablab was planted with two seeds per hole, 9 days after maize on March 23, 2018. Lablab accessions were planted row-to-row distance of 90 cm and a plant-to-plant distance of 50 cm within rows. Lablab rows were located equidistant between maize rows in intercropped plots. The maize variety Pannar 15 was planted in 6 rows per plot with row-to-row distance of 90 cm with two seeds per hole for a total of 44,444 seeds per ha. One guard row of maize was planted along plot edges to minimize edge effect whether lablab was adjacent to maize plots or not. Maize was fertilized in planting holes at a rate of 40 kg/ha of di-ammonium phosphate (18-46-0). Lablab received no fertilizer in the planting holes.

Block 1							Block 2							Block 3					
1	**2**	3	4	5	6		1	2	3	**4**	5	6		**1**	**2**	**3**	**4**	**5**	**6**
12	**11**	**10**	**9**	**8**	**7**		**12**	**11**	**10**	**9**	**8**	**7**		12	11	10	9	8	7
13	**14**	**15**	**16**	**17**	**18**		**13**	**14**	**15**	**16**	**17**	**18**		13	14	15	16	17	18
24	23	22	21	20	19		24	23	22	21	20	19		**24**	**23**	**22**	**21**	**20**	**19**
25	26	27	28	29	30		**25**	**26**	**27**	**28**	**29**	**30**		25	26	27	28	29	30
36	**35**	**34**	**33**	**32**	**31**		36	35	34	33	32	31		**36**	**35**	**34**	**33**	**32**	**31**
37	**38**	**39**	**40**	**41**	**42**		37	38	39	40	41	42		**37**	**38**	**39**	**40**	**41**	**42**
48	47	46	45	44	43		**48**	**47**	**46**	**45**	**44**	**43**		48	47	46	45	**44**	43

= intercrop with maize

Figure 6: Layout of the field experiment at Mungushi, Tanzania. The block layout is by plot number. The white cells indicate sole lablab and yellow cells indicate lablab intercropped with maize.

The plant development stage of flowering was recorded as time to 50% flowering of the plant stand in number of days after planting (DAP). Insect pests were monitored closely beginning at flowering stage, and insecticides were applied when populations reached presumed damaging levels. The site was sprayed a total of four times on April 17, May 17, June 14 and July 28 to control damaging insects beginning at early pre-flowering to pod forming stage with the recommended rate of Dudu-all; active ingredient: cypermethrin 10% + chlorpyrifos 35%. All plots were kept weed-free by hand hoeing.

Figure 7 Field trial site in 2018 at Mungushi, (Arusha region) Tanzania. Planted to vigorously growing sole lablab or maize-lablab intercrop. Picture taken May 9, 2018. Photo: Chris Forsythe

4.3.4 Insect sampling

Intensive insect pest sampling was conducted approximately every 14 days starting at time of first flower stage, totaling seven different sample dates. Sampling began when at least 10 plants per plot had an open flower. The choice to begin at first flowering was because the plants are most vulnerable to economic loss from pest attacks during the reproductive stages (Miller et al., 2018). The sampling period was 52 DAP to 125 DAP. Ten inflorescences were selected at random from each plot in an N shaped pattern and each tapped 7-10 times on the inside of a 10L plastic bucket and the number of each type of insect pests was collected was recorded. The level of infestation of the main damaging lablab insect pests including thrips, aphids, pod sucking bugs and pod borers was determined. Aphid infestation was based on the number of plants out of 10 randomly sampled inflorescences with aphids present on stems or leaves.

4.3.5 Data analysis

The data obtained from the observations was compiled and the single maximum count per observation was used in the first analysis (i.e. each accession per block and sole crop/intercrop). Maximum counts were chosen as the data for analysis as opposed to an average or cumulative value because of unequal time to flowering among accessions; therefore, an unequal number of sample dates per accession was collected. Data was subjected to statistical analysis using univariate analysis of variance (UNIANOVA) method using the statistical software program IBM SPSS Version 23. The dependent variable was ‘maximum insect count’ and was transformed by adding one and taking the 10-logarithm to be more normally distributed. The fixed factors were ‘accession’ and ‘sole-crop/intercrop’ (i.e. sole crop or intercrop with maize). A random factor was used and was called ‘block’ to account for the split-plot design. The model included an interaction effect between accession*sole-crop/intercrop as well as an interaction between block*sole-crop/intercrop due to the split-plot design. Differences were considered significant when $p < 0.05$. For parameters with a significant (P<0.05) F-statistic for the accession main effect, individual accession performance was further separated using the least significant difference method (P=0.05).

A second UNIANOVA test was conducted in an attempt to reduce the effect of the variability among accessions in time to 50 % flowering. This was achieved by grouping the 21 accessions into ‘early’ ‘medium’ and ‘late’ based on mean time to 50% flowering (DAP), then each flowering group was analyzed separately. Maximum insect count values were again used as the dependent variable but only included in the analysis were maximum insect counts sampled after the accession’s time to 50% flowering. Only sole crop flowering data was used since intercrop delays time to flowering significantly. The model used in the second test was the same as the first test except the second test only used sole crop data; therefore, ‘sole-crop/intercrop’ and interaction including that factor were not included.

5. Results

5.1. Structured interviews

5.1.1. Social classification of the respondents

While strong differences among the study villages were found, it was chosen to make an overall analysis to be more representative of the whole study region.
Of the 28 respondents interviewed, four were female and 24 were male. The ages of the respondents were as follows: 28% in the age range 26-40; 67% in the age range 41-60, and one (3%) was over 61 years. The average number of people living in a household was six, with a range of three to 14 people. The farmers interviewed were very experienced with an average number of years spent farming of 22 and 33% of respondents had over 30 years farming experience. Most of the respondents reported that farming was the sole means of household income at 86%, while 14% said they own a small business in addition to running the farm[1]. Family labour was involved in all farming activities with 79% reporting that they used both family and paid labour while 21% used only family labour.

[1] This response may be misleading because it was explained by a knowledgeable informant that some farmers may not care to admit to outsiders that they have a side business due to tax repercussions from the authorities.

5.1.2 Farming system overview

The total arable crop land available (rented or owned land) for each farm ranged between 0.4 ha and 6 ha with an average of 2.2 ha. It was found that 50% of farms had less than 2 ha, 43% were between 2 ha and 4 ha and only 7% (two farms) were larger than 5 ha.

Beyond the staples, the farm gate price and the weather conditions at planting time determine to a large extent which crops are planted and which are not. In 2018, almost all farms included maize (either sole or intercropped with a legume) in their farm at 86%. This was similar to the number of farms that included lablab, at 82%. The types of crops grown by the respondents in the 2018 season were (in order of most to least used and the numbers in brackets show how frequently the crop was mentioned): maize (24), lablab (23), common bean (11), pigeon pea (*Cajanus cajan*) (8), sunflower (*Helianthus annus*) (5), mung bean (*Vigna radiate*) (4), cowpea (4), millet (*Pennisetum glaucum*) (4), onion (*Allium cepa*) (3), sugarcane (*Saccharum officinarum*) (1), tomato (*Solanum lycopersicum*) (1), sweet potato (*Lpomoea batatas*) (1), groundnut (*Arachis hypogaea*) (1) and sorghum (*Sorghum bicolor*) (1). In total, six legume species were reported by the participating farmers.

There were strong regional differences in the types of crops grown. For example, at the Mungushi village in 2018, all farmers interviewed had grown mung bean. At the site of Karatu none of the four participating farmers had planted lablab in 2018. Two out of the four respondents provided the reason of a “poor market price” for not growing lablab.

Most farmers keep some kind of livestock including cows, goats, sheep, donkeys, chickens and pigs. One farm even had a small fish farm for income. After harvest the residue becomes communal grazing for livestock and this practice makes planting perennials or cover crops difficult. Most farmers grow vegetables and have fruit trees for home consumption. None of the participating farmers reported using inorganic fertilizer on their crops. If any fertilizer was used it was in the form of animal manure or compost. However, fertilizing crops was not found to be common.

Generally, it was discovered most maize grown was used for home consumption while for other crops (e.g. common bean, lablab, onion, tomato), more was sold than was used for home consumption suggesting farmers were counting on these crops primarily for income generation. Overall, farmers sold most of their lablab grown in the 2017 season with an average of 89% of grain sold at the farm gate right after harvest, while only 11% was used for home consumption or to save seed for the following season.

Only 7% of participating farmers indicated that they deliberately practiced a crop rotation, but it was very short (two years or less between the same crop species on the same land parcel) (Figure 9). Of the remaining farmers, more than half indicated they either did not understand how to practice a crop rotation, or they understood the concept but chose to not follow a rotation.

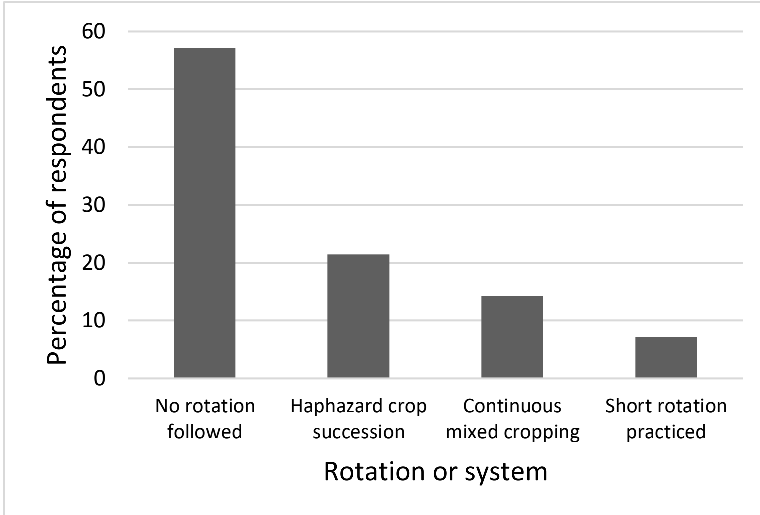

Figure 8 Percent response of type cropping system or rotation followed. A short crop rotation is defined as a maximum of 2 years between different crop species on the same field.

A large proportion of farmers practice intercropping (68%) and some even grow all crops on the same land parcel. For example, one farmer grew maize, common bean, mung bean and sunflowers all together with Mexican marigold (*Tagetes erecta*) to act as a natural pest deterrent (Figure 8). When intercropping was practiced it was reported to be out of necessity, due to "land scarcity".

Figure 9 This farmer uses a polyculture system by having 5 different species growing simultaneously on the same parcel. Mexican marigold (*Tagetes erecta*) held in the farmers hand acts as a biological insect pest control. Elkushi village (Arusha city region), Tanzania, May 2018. Photo: Chris Forsythe

5.1.3 Lablab production system and importance

Of the farmers who grew lablab in 2018, the mean proportion of lablab to the total arable farm size was just over half at 54%. The area planted to lablab relative to total farm size ranged from 6% on one farm while others had it on 100% of their land. The amount of lablab produced relative to farm size increased as farm size increased. The mean area under lablab production for farms less than 2 ha was 0.56 ha and for farms greater than 2 ha, the mean area under lablab was 1.2 ha.

The group of farmers who chose to grow lablab as an intercrop (with two species) with maize was highest at 43%. The proportion who grew it as sole crop was 35%; followed by 13% who had both intercrop and sole crop and finally 4% grew lablab in a mixed crop (more than two species) situation (Figure 11).

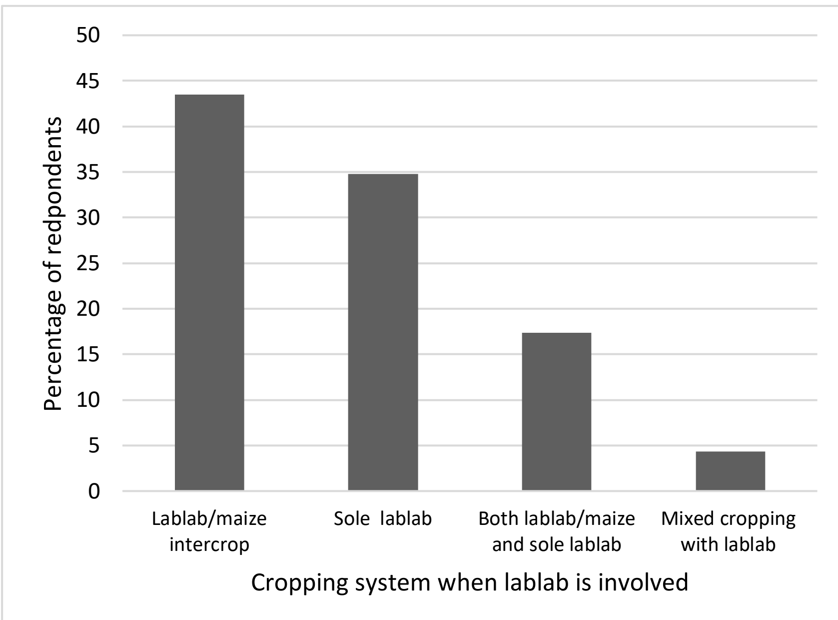

Figure 10 Percent response of cropping system used when lablab was involved

The number of years the farmers have been growing lablab varied, with 71% reporting they have been growing lablab for less than 10 years and 29% replied they have been growing lablab for 10 years or more. Lablab has been a part of the family farm history with 64% reporting their parents have grown the crop.The question of whether the farmers' grandparents have grown lablab in the past was not asked but at least two respondents volunteered that their grandparents had been lablab growers.

The names of the most commonly grown lablab accessions are not known because the name is not known to the farmers since most save their own seed (85%) and have been doing so for a long time. Another source of seed is from researchers at SARI who are administering the on-farm trials (18%); 13% buy unknown types at the local market; 13% get seed from another farmer; and 3% from the Arusha city market. However, the black seeded types matter for export to Kenya so, expectedly, 85% were black seeded and 11% were white seeded while 4% of farmers reported they grew both black and white seeded types.

Knowledge about growing lablab came from many sources, including: 32% who responded they get it from other farmers or neighbours (i.e. sharing of local knowledge), 25% responded it was passed down from their parents (i.e. indigenous knowledge), 25% responded it was from agricultural researchers, 14% responded it was from local extension officers and finally 3% responded it was from NGOs.

5.1.4 Motivation and constraints for growing lablab

The participants were asked to place a maximum of 10 beans in any number or combination inside a box beside a provided list of answers for their opinion of what the main reasons and what the main constraints are for growing lablab.
The number one reason for growing lablab was found to be ‘sell for money’. This was followed by home consumption, drought tolerance, animal fodder, soil cover and other (soil improvement was the answer mentioned) (Figure 12).

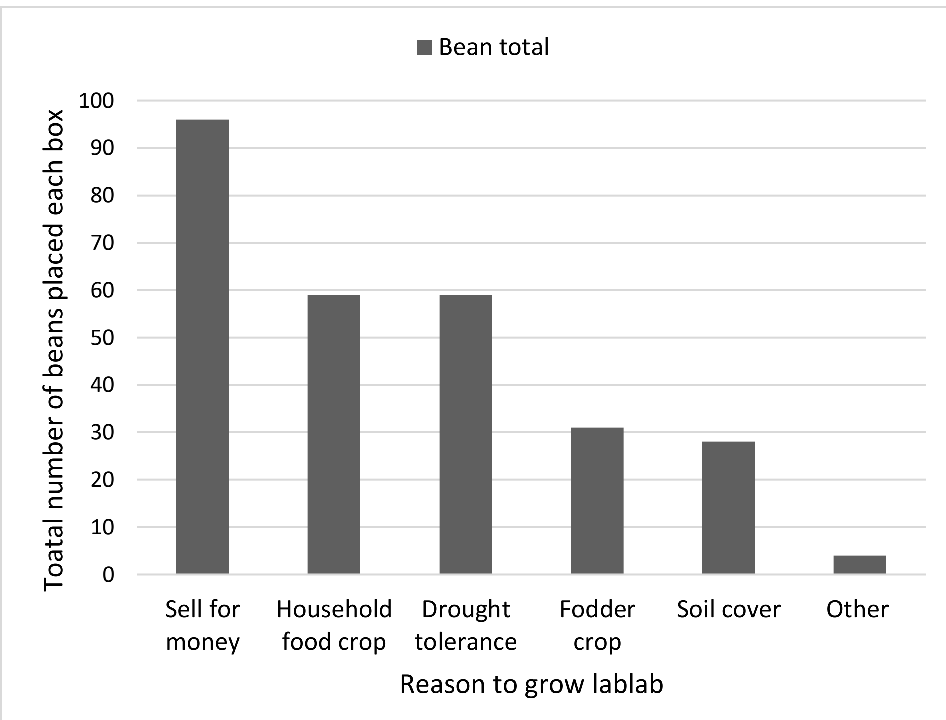

Figure 11 The main reasons for growing lablab identified by respondents by putting beans in a box in any amount beside the reason given.

The number one main reason to grow lablab was for income. Similarly, the most mentioned constraint was the ‘poor market/price’ (Figure 13). These results highlight the high importance of lablab as a cash income source for households. The next most mentioned constraint was the ‘cost of inputs’ which was specified to be more about the cost of buying chemical insecticides than for any other inputs such as seed and fertilizer, since these are not often purchased. Insect issues (i.e. damage) was next followed by weather or climate, poor varieties, lack of available seed, weeds and other (lack of mechanization, lack of labour and lack of land were all mentioned once).

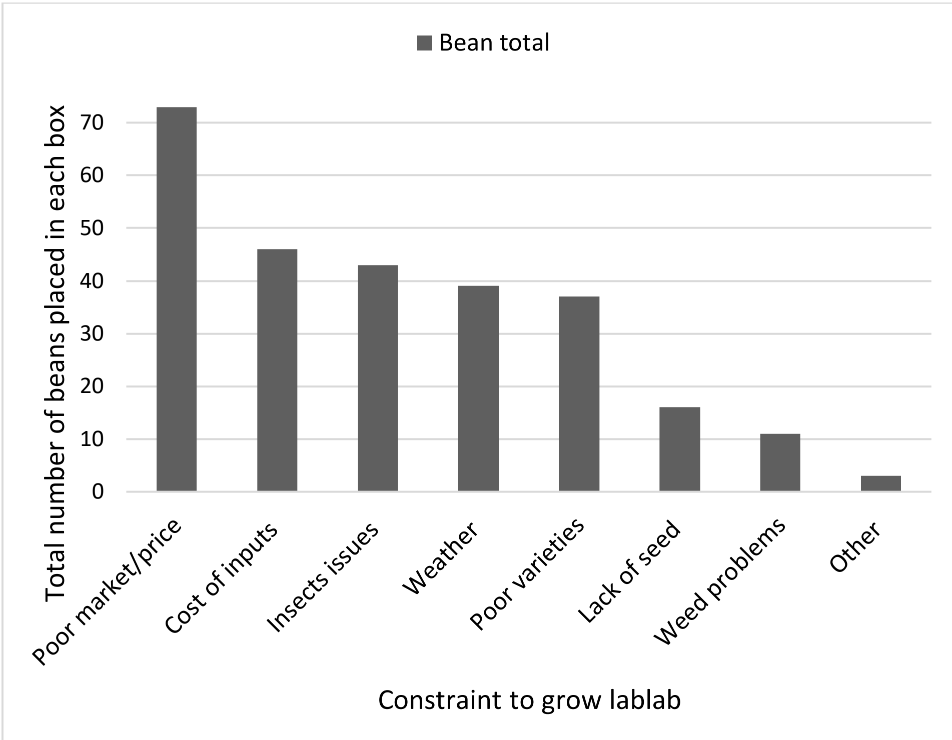

Figure 12 The main constraints for growing lablab identified by respondents by putting beans in a box in any amount beside the constraint given.

The last question asked in the survey was: will you continue to grow lablab in the future? The responses were overwhelmingly positive at 96% with only 4% stating that they would not grow lablab anymore providing the reason of a "poor market". The caveat for many of the positive replies was "I will only grow lablab if there is a good market" suggesting that the market price is of utmost importance to them in their decision making.

5.1.5 Consumption habits

Home consumption of lablab is frequent among respondents with 70% eating it more than once per month. The form of lablab that is most eaten is the grain at 76% while less, 24%, eat the grain, leaves and pods (Figure 14).
Most respondents (55%) did not know what nutritional benefits lablab provides, saying they only knew it to be a "food source". Some on the other hand knew it was a medicine (14%), an energy source (11%), a protein source (11%), a vitamin source (3%) and a source of carbohydrates (3%).

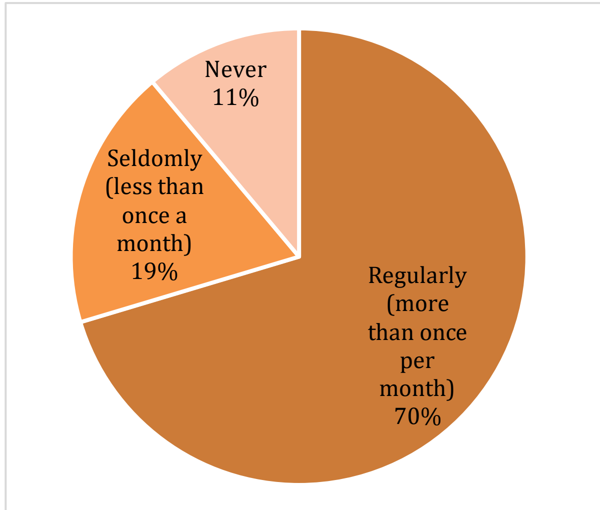

Figure 13 Frequency of lablab home consumption.

5.1.6 Insect management

Farmers rely very heavily on insecticides, stating that if no insecticide is applied there is either a total loss or a reduction in yield caused by defoliation by harmful insects (59% and 41% respectively).

In total, 10 different insect pests were mentioned as most damaging to lablab (Table 2). The insect that was identified as being the most damaging of all insect pests was pod borer during the stages of flowering and pod forming (mentioned by 43% of respondents). Proper pest identification was difficult to obtain as sometimes the name was not known or conveyed in the local language and lost in translation. Eventually, as more interviews were completed the interviewer started showing pictures of insects to the respondents for proper identification. For example, 'caterpillar' may have meant pod borer since they are similar looking.

Table 2 The types of pest insects reported to cause damage to lablab, the frequency mentioned, the stages of attack and the type of damage they cause; ***** Pod borer was usually identified as African bollworm (*Helicoverpa armigera*).

Pest name	**Response (%)**	**Stage(s) of attack**	**Type of damage**
Pod borer*	43	flowering, pod forming	eats leaves and bores holes
Caterpillar	21	flowering	eats flowers
Aphid	15	prior to flowering, flowering	makes leaves yellow; covers stems and leaves causing shrinkage
Army worm	14	flowering	eats leaves
Thrip	13	prior to flowering, flowering	damages and stunts plants
Beetle	7	after harvest	n/a
Cutworm	4	seedling	cuts stem
Green insects that eat flowers and then pods	4	flowering and pod forming	n/a
Green defoliator	4	leaf	defoliation
Butterfly looking pest	4	flowering and pod forming	n/a

Insect pest control is overwhelmingly carried out by chemical insecticide mentioned by 86% of respondents. Furthermore, half of respondents spray at least twice, 17% apply insecticide three times and 8% said they apply insecticide four times (Figure 15). When asked the question "other than chemical insecticide, what forms of control do you use?" most replied that they "did not know any" other forms of control (Figure 16). However, for the farmers who did use alternative control methods, they used methods such as ashes for applying on plants and on soil around plants. They also used biological control agents such as neem trees to act as a perimeter around land parcels or neem seeds crushed up and made into a foliar spray. The neem tree is a known insect repellent. One respondent even replied, "I use fermented cow urine and then hot pepper."

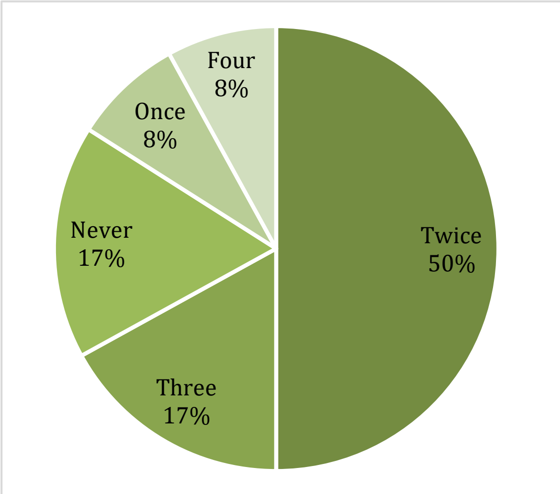

Figure 14 The number of pesticide applications performed by farmers who use pesticides for insect control

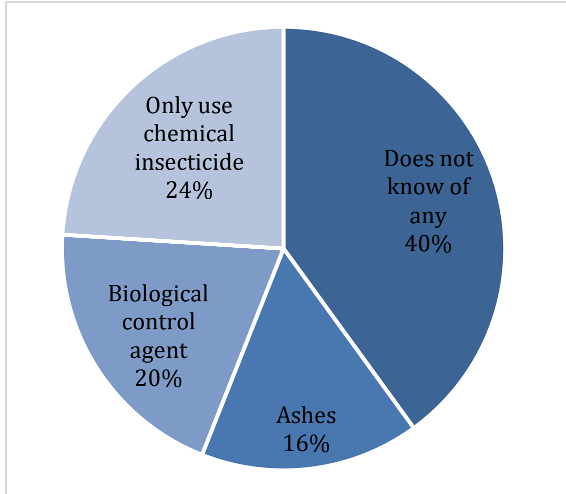

Figure 15 Responses for forms of insect control used when asked "other than insecticides what kind of control methods do you use?"

Intercropping lablab with maize was generally not as often perceived as being helpful towards reducing insect damage compared to sole crop lablab. 67% of respondents claimed intercropping did not reduce insect damage in lablab while 33% claimed that intercropping did help in reducing insect damage. One response in support of an intercrop was "insect damage is reduced because the insects infest the maize and leave the lablab alone." Another farmer said, "maize pollen falls in lablab and insects are repelled." Another response was that in intercropping "insects do not like the environment." On the other hand, there was the notion that two hosts instead of one can mean potentially higher infestation levels of damaging insects "more damage is caused because each crop species has its own insects." Others simply replied they saw no difference between the two cropping methods.

Farmers were asked an open-ended question about how lablab varieties can be improved. The most common answer was that they want a higher yield (25%), followed by a shorter maturity time (20%), better disease resistance (18%) and more drought tolerance (14%). The matter of more insect resistance needed was surprisingly low at only 4% of responses. This suggests that either the insecticides are considered to be effective or perhaps farmers are not aware that insect resistant genotypes exist.

5.1.7 Market matters

Almost every farmer (96%) stated that they can *always* sell their lablab at the farm gate with only 4% saying they may not always be able to sell their product.

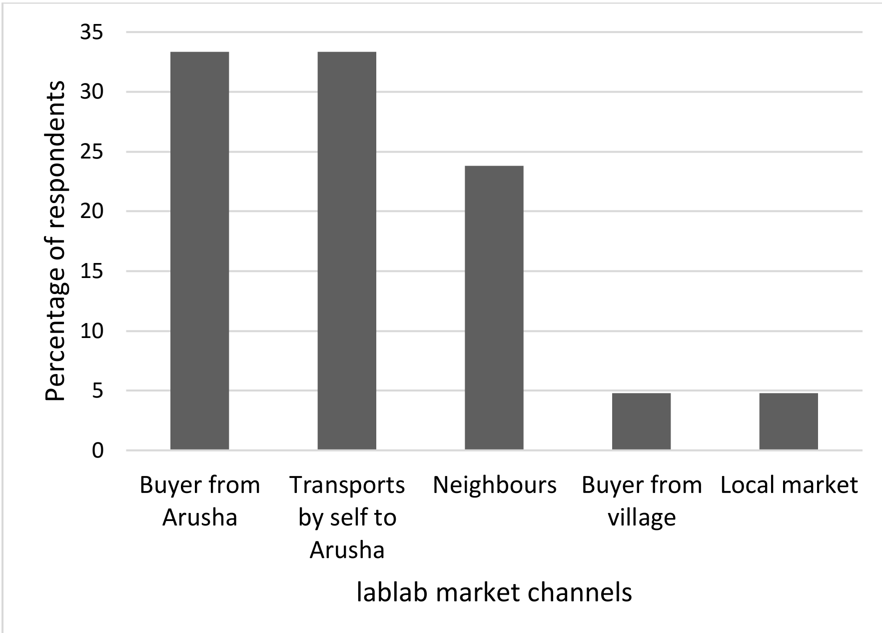

Figure 16 The marketing channels farmers use for selling their lablab product.

Most often, the product is sold to a buyer who comes to the local village. This was reported by 33% of respondents (Figure 17). Many others (33%) arrange to have it transported (because they do not have their own trucks) to Arusha themselves by-passing the ‘middle-man’. This method is often done when a group of farmers bulk their lablab grain (and other products) together to fill a truck in order to get a higher price. However, a large portion of lablab is sold locally to neighbors (24%), buyers from village (5%) and the to the local market (5%) where the seed is used for planting the next season or for home food consumption.

Farmers were very aware of where their product ends up, with 68% and 26% reporting that their product ends up in Kenya and Arusha respectively (it is speculated that from Arusha it all goes to Kenya). Only 5% were unsure as to the final destination of their lablab.

Eighty-two percent of respondents mentioned were not likely to form cooperatives to help them gain a better market price and reduce transportation costs. The most common reason provided for not forming a cooperative was “I have not received the education about how to form a cooperative.” However, a small percentage of farmers reported they do form cooperatives to help move their product (18%).

Farmers were asked to recall the price in Tanzanian shillings (TSh) per 90 kg bag of lablab for the past three years (Figure 18). On average, of all responses, it was found that the market price fluctuated considerably. They recalled the price to be 105,000, 175,000 and 150,000 TSh in 2017, 2016 and 2015 respectively for an average of 143,000 TSh per 90 kg bag over the three years (100,000 TSh = $43.47 USD). This was in contrast to the reported price of maize and common bean at 90,000 and 100,000 TSh per 90 kg bag respectively in 2017.

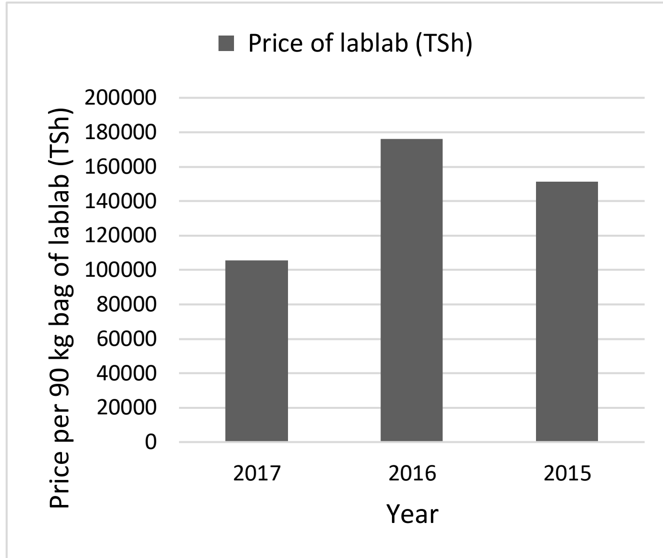

Figure 17 Market price (TSh) recalled by farmers for one 90 kg bag of lablab grain for the past three years (i.e. 2015-2017) (100,000 TSh = $43.47 USD).

5.2 Informal interviews

5.2.1 Interview with a healthcare professional

A public health nurse who was working at the Selian hospital in Arusha city with Maasai children from rural semi-arid Tanzania was interviewed. The children were suffering from acute malnutrition called kwashiorkor, caused by a protein deficiency. According to the nurse the Maasai diet is largely animal product based and other foods they usually eat to get full is ugali, a maize porridge. Cereals are lower in protein, zinc and iron compared to legumes (Odendo et al., 2011). She spoke about how it is not so simple just to plant and eat legumes for protein:

"The people are not food secure. The soil is too poor to grow beans. Trees don't grow because the soil is too shallow. If they could grow beans the men do not help to grow the crops and goats would come and eat it all since the women are too weak from lack of food and energy to protect the crop. The men get the meat and keep all the money earned from selling the animals and the women eat ugali and have to forage the forest for greens. (…) A household may have three wives, 10 children to feed and one woman works for 6,000 TSh per week" (6,000 TSh = $2.60 USD), this is not enough to feed a family. (…) They need education on healthy diets and money for social programs. They need more support. They could grow valuable nutritious crops such as chia that are worth protecting."

5.2.2 Interview with a grain trader

An interview took place with a grain export trader who was filling bags of lablab grain at Ngaramtoni market in Arusha region and transporting the bags to Kenya by truck. The lablab was purchased at either the market from buyers who received the product at the farm gate or from the farmers directly.

"The lablab is all going to Kenya and the price is 90,000 TSh per 90 kg bag (90,000 TSh = $39 USD). I only sell lablab to Kenya and they only want black seed. In Tanzania they all want white seed."

He was shown samples of other coloured lablab seeds and seemed interested in these for the local Tanzanian market. It was unclear what price he was selling the bags of lablab for in Kenya.

5.2.3 Interview with a government extension officer

A local agricultural extension officer in the village of Hedaru, Kiliminjaro region was interviewed about extension services and lablab production in his area. He was knowledgeable about the special needs of his drought-prone area and was motivated to intensify by conventional methods production:

"We measure our performance with the quality and amount of advice we give and the productivity of the farmers. We are advising them on things such as proper planting timing, row spacing and which inputs (fertilizer and chemicals) to use. (…) Lablab is one of the only cash crops that can be grown in the area because it is drought tolerant. As a result, most farmers grow only sole lablab and maize here. (…) Farms are becoming more than just subsistence, they are being run more like a business to make profit."

5.2.4 Interview with a conservation agriculture officer

An interview took place at Ngaramtoni, near Arusha city with a conservation agriculture technology officer. He is overseeing the on-farm lablab accession trials in order to select improved types to make seed increases and then make them available to farmers:

"There are 1000's of lablab accessions so we need to test the ones we think are 'best bet' for Tanzania. (…) Other issues that we work on are lablab grain taste trials to improve palatability. (…) There needs to be a more stable market for lablab. There are large price swings of 90,000 to 300,000 TSh per 90 kg bag because the Kenyan export market gets saturated. Getting Tanzanians to eat lablab from the local market is huge. There needs to be campaigns to change eating habits with new recipes using lablab. (…) Improved insect pest control practices are also needed. Farmers spray insecticide sometimes up to three times when the crop is flowering and at pod forming stage." (Conservation agriculture technical officer, CFGB).

5.3 Field trial results

5.3.1 Time to flowering

Intercropping lablab with maize delayed time to flowering compared to sole cropped lablab. There were significant differences among lablab accession time to 50% flowering with a range from 41 to 118 DAP for sole crop ($F(20) = 5.8$, $P<0.0001$) and a range from 52 to 127 DAP for intercrop with maize ($F20) = 14.4$, $P<0.0001$) (Table 3).

Table 3 Accession time to 50% flowering for sole lablab and lablab intercrop with maize at Mungushi site. Also included are the flowering groups (early, medium and late) to which each accession has been assigned to based on their mean time to flowering in sole crop.

Accession ID	50% flowering (DAP) sole crop	50% flowering (DAP) intercrop	Flowering group (sole crop)
Q 6880B	41	76	Early
H1	43	52	Early
CPI 81364	53	66	Early
Eldoret Black 1	57	79	Early
Karamoja White	58	78	Early
DL1002	59	71	Early
Eldoret Black 2	59	68	Early
Highworth	60	74	Early
Karamoja Red	70	78	Medium
ILRI 6930	72	92	Medium
SARI Rongai	73	88	Medium
CIAT 22759	74	95	Medium
ILRI 14437	75	83	Medium
Karatu Black	76	88	Medium
ILRI 6536	85	118	Late
DL1001	88	112	Late
Rongai	91	110	Late
Echo Cream	94	119	Late
PI 195851	96	118	Late
Dodoma white	106	124	Late
R1	118	127	Late
Means	74	91	

5.3.2 Relationship of relative maturity to insect infestation level

The relationship of relative maturity (time to 50% flowering) to total of the mean maximum counted insects for all species showed a general trend of eary-flowering accessions having higher counted insects compared to late-flowering accession (Figure 19). This correlation was not strong, although the strongest correlation was seen in the pod borers. Data trends were not analyzed for significance.

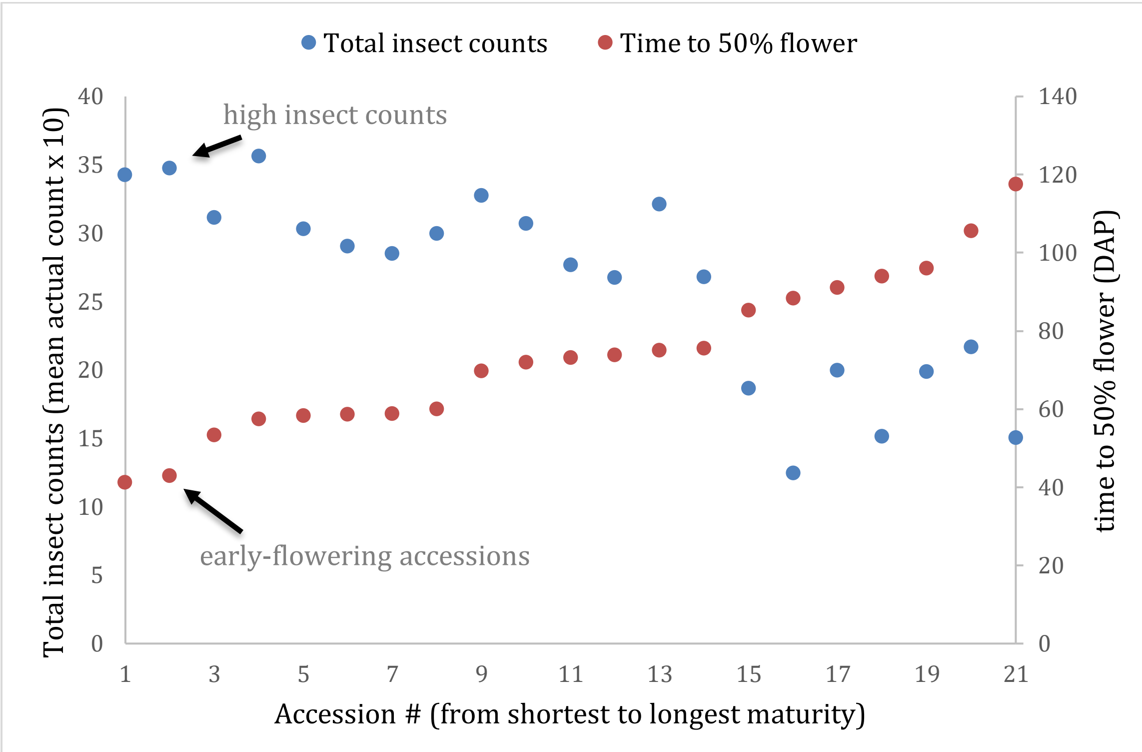

Figure 18 Total insect infestation levels by accession time to 50% flowering (DAP). Means of each max insect counts were summed and multiplied by 10 to fit on the same chart as the flowering data.

5.3.3 Infestation levels of major insect pests on different lablab accessions based on time to flowering

Accessions were divided into three different maturity groups of early, medium and late based on their relative time to 50% flowering in order to reduce the variability of insect infestation levels (Table 3).

5.3.3.1 Thrips

Counts of thrips varied significantly among accessions in the early flowering group ($F(7)=3.8$, $P<0.05$) (Figure 20). From this group, the accession with the least number of counted thrips was Karamoja White and the highest was Highworth. There were no significant thrip count differences among accessions in the medium and late flowering groups.

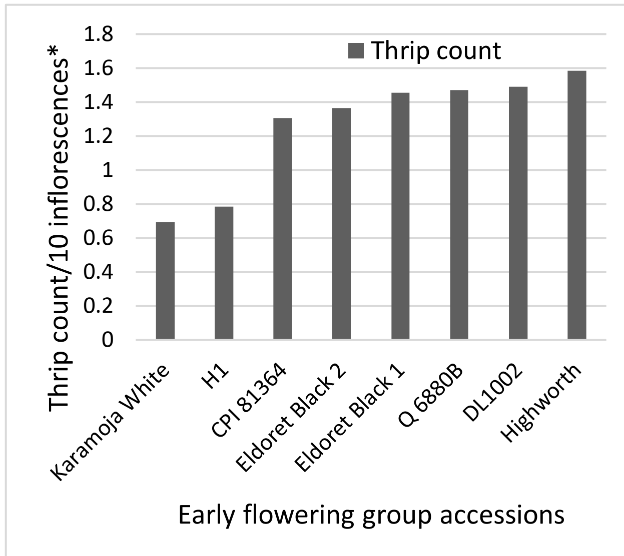

Figure 19 Counts of thrips per accession in sole crop belonging to the early flowering group; *values were $\log_{10}(y+1)$ transformed.

5.3.3.2 Aphids

There were no significant differences in numbers of aphids among accessions in the early, medium and late flowering groups.

5.3.3.3 Pod sucking bugs

Pod sucking bug counts were too low in the early flowering group to conduct data analysis to differentiate among accessions. While pod sucking bug counts were high enough in the medium and late flowering groups, there were no significant differences among accessions.

5.3.3.4 Pod borers

There were significant pod borer count differences among accessions in the late flowering group ($F(6,) = 4.2$, $P<0.05$). From this late flowering group, the accessions with the least number of counted pod borer individuals were DL1001 and PI 195851 each with zero and the highest was ILRI 6536 with a mean of two (Figure 21). There were no significant pod borer count differences among accessions in the early and medium flowering groups.

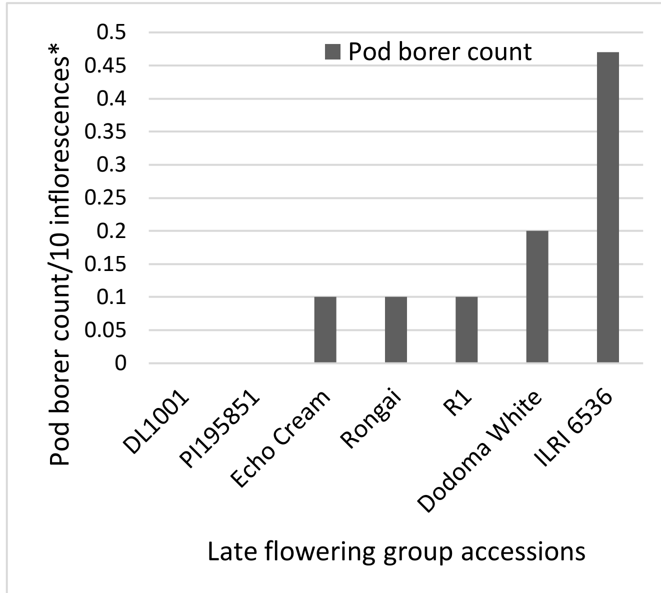

Figure 20 Counts of pod borers per accession in sole crop in the late flowering group; *values were $\log_{10}(y+1)$ transformed.

5.3.4 Infestation levels of major insect pests on different lablab accessions in sole crop or maize-lablab intercrop

5.3.4.1 Thrips

Overall, there were significant differences among accessions with respect to counts of thrips ($F(20) = 4.74$, $P<0.0001$), ranging from 1.6 to 36.6 (DL1001 and Highworth respectively) individuals per 10 inflorescences (Figure 22). Additionally, intercropping had a strong effect on thrip infestation levels. Counts were significantly higher in sole crop ($F(1) = 40.9$; $P = 0.024$) with a mean of 23.8 ± 1.7 compared to 6.3 ± 1.7 thrips in intercrop (see Table 4). There were no significant differences among blocks, or any significant interactions between sole-crop/intercrop*block or accession*sole-crop/intercrop.

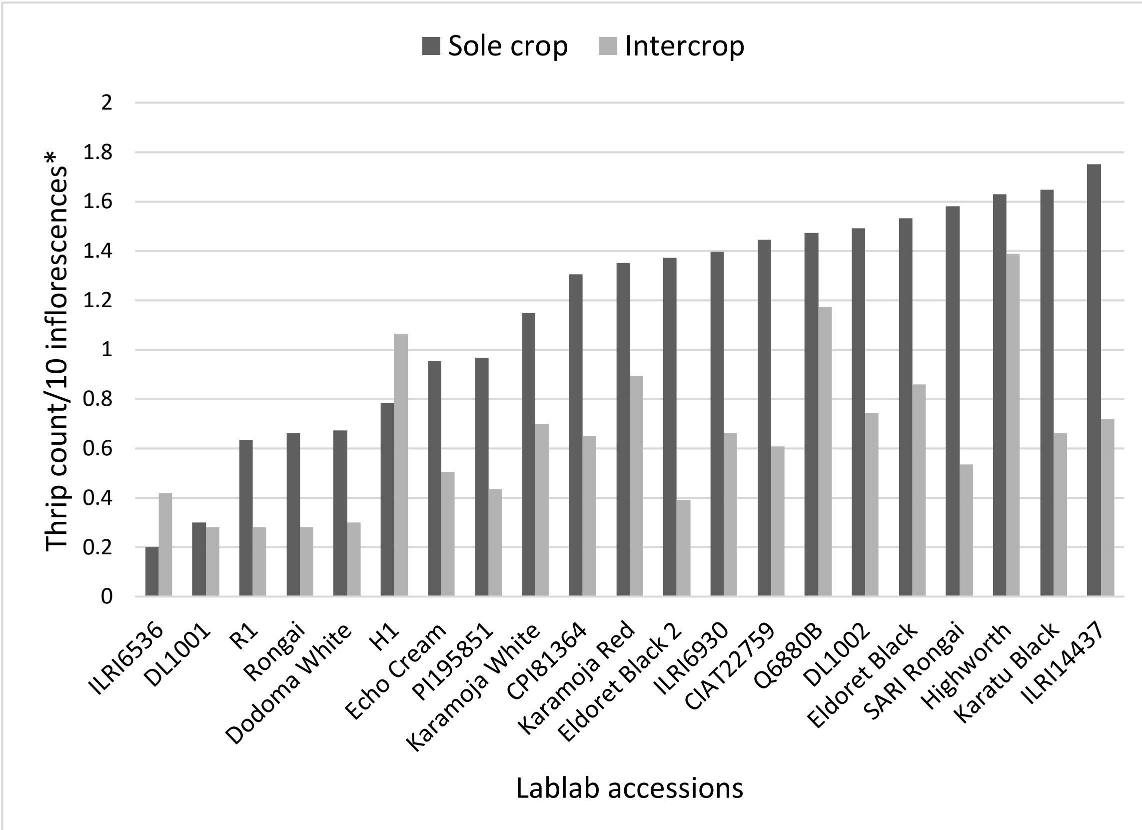

Figure 21 Counts of thrips per 10 inflorescences for sole lablab or intercrop (maize and lablab); *values were $\log_{10}(y+1)$ transformed.

5.3.4.2 Aphids

Overall, there were significant differences among accessions with respect to aphid infestation levels ($F(20) = 1.74$, $P<0.05$), ranging from 0.5 to 4.3 (Echo cream and H1 respectively) plants per plot with at least one aphid present (Figure 23). There were significant differences among blocks ($F(2) = 22.45$, $P<0.05$). There were no significant differences between sole crop and intercrop (see Table 4), or any significant interactions between sole-crop/intercrop*block or accession*sole-crop/intercrop.

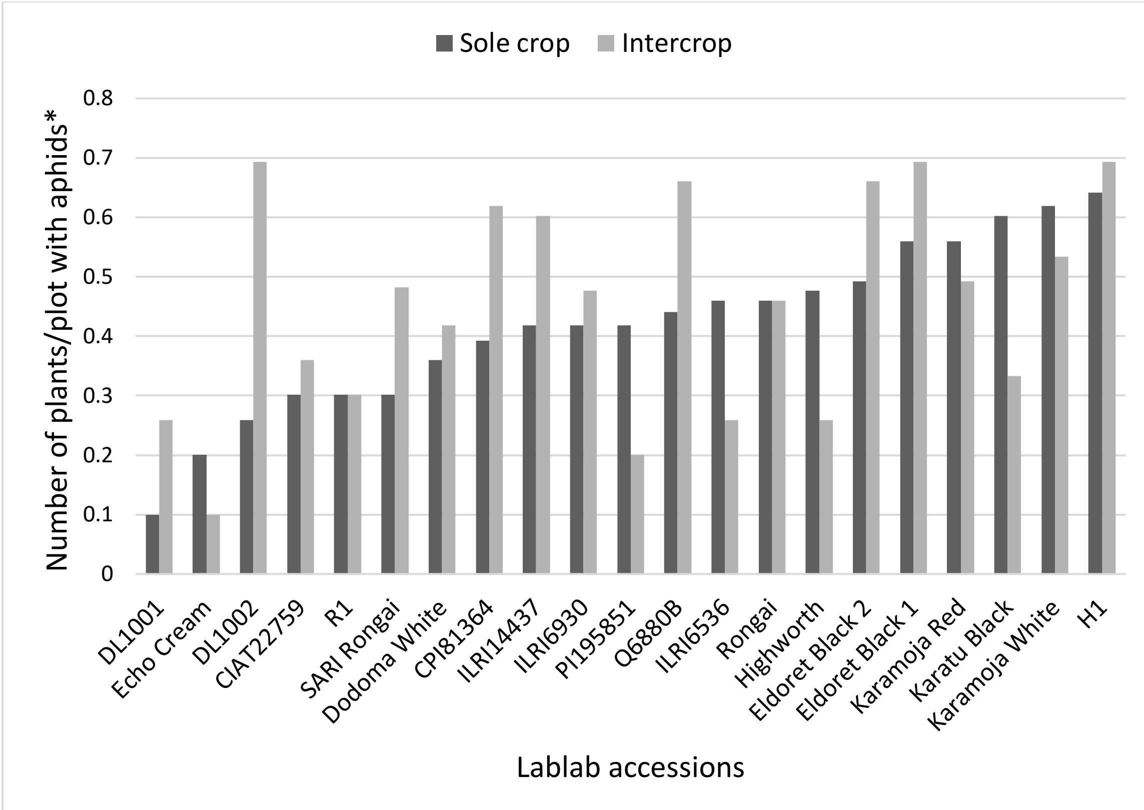

Figure 22 Number of plants per plot with aphids present for sole lablab or intercrop (maize and lablab) accessions; *values were $\log_{10}$ (y+1) transformed.

5.3.4.3 Pod sucking bugs

Overall, there were significant differences among accessions with respect to pod sucking bug counts ($F(20) = 2.1$, $P = 0.0103$), ranging from 4.2 to 22.3 (Echo Cream and Karamoja Red respectively) individuals per 10 inflorescences (Figure 24). Additionally, intercropping had a strong effect on pod sucking bug infestation levels. Counts were significantly higher in sole crop ($F(1) = 23.5$, $P<0.05$) with a mean of 17.64 ± 1.3 compared to 8.65 ± 1.3 pod sucking bug individuals in intercrop (see Table 4). Echo cream had zero pod sucking bugs in the intercrop. There were no significant differences among blocks or any significant interactions between sole-crop/intercrop*block or accession*sole-crop/intercrop.

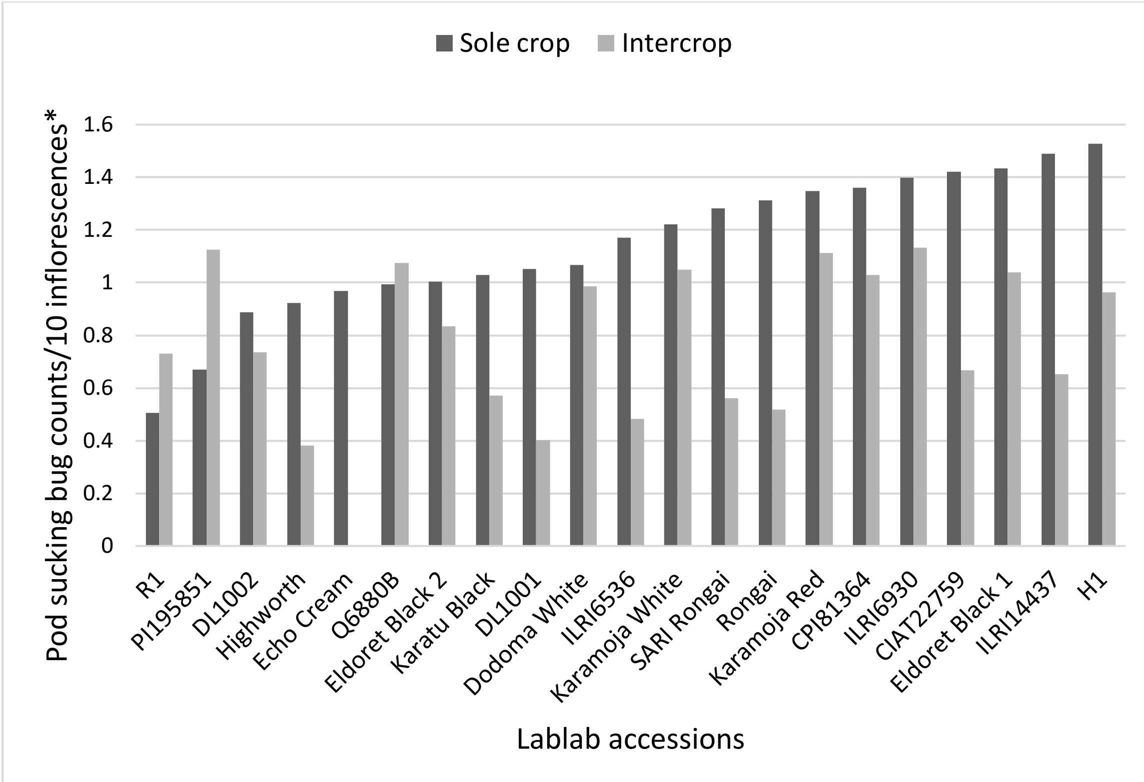

Figure 23 Counts of pod sucking bugs per 10 inflorescences for sole lablab or intercrop (maize and lablab); *values were $\log_{10}(y+1)$ transformed.

5.3.4.4 Pod borers

Overall, there were significant differences among accessions with respect to pod borer counts ($F(20) = 3.7$, $P = 0.00001$), ranging from 0.17 to 3.6 (DL1001 and H1 respectively) individuals per 10 inflorescences (Figure 25). While there were lower pod borer counts in intercrop in 16 out of 21 accessions the mean differences were not statistically significant (Table 4). There were no significant interactions between accession*sole crop/intercrop. However there were significant interactions between sole crop/intercrop*block ($F(2) = 5.82$, $P = 0.004$).

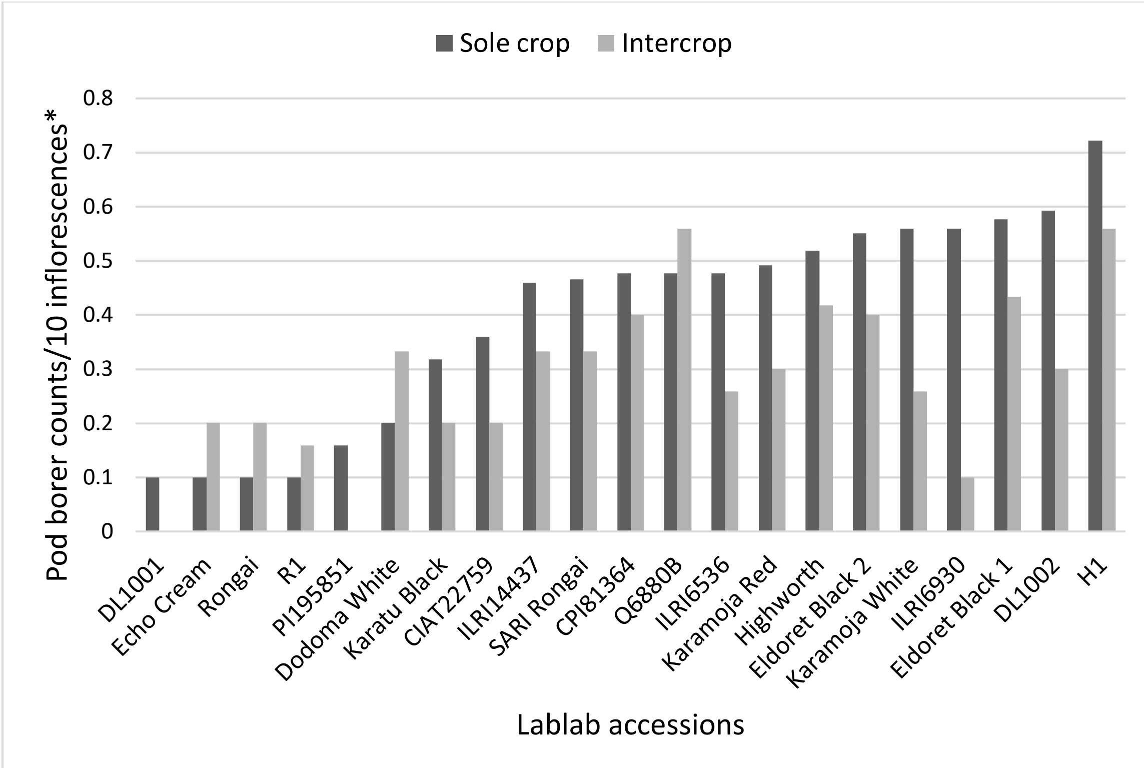

Figure 24 Counts of pod borers per 10 inflorescences for sole lablab or intercrop (maize and lablab); *values were $\log_{10}(y+1)$ transformed.

Table 4 Means (SE±) of counts of insect individuals from each major species in sole crop or intercrop (maize and lablab) lablab accessions. Means with the same letter within the same row are not significantly different at a<0.05; *Number out of 10 plants per plot with aphids present.

	Means (SE±) of counts of individuals per 10 inflorescences/plants	
Species	Sole crop	Intercrop
Thrips	$23.8 \pm 1.7_a$	$6.3 \pm 1.7_b$
Aphids*	$2.0 \pm 0.2_a$	$2.5 \pm 0.2_a$
Sucking bugs	$17.6 \pm 1.3_a$	$8.6 \pm 1.3_b$
Pod borers	$1.8 \pm 0.1_a$	$1.2 \pm 0.1_a$

6. Discussion

6.1 Insect study

Which are the major insect species causing damage to lablab in Tanzanian farming systems and do they prevent production?

Review of literature revealed that legumes in Africa are a host to many different economically damaging insects that are severely hampering their production (e.g. Abate and Ampofo, 1996). The reproductive stages of lablab, during flower and pod forming, are the most vulnerable plant stages to insect attack resulting in enormous amounts of yield loss when not properly managed (Miller et al., 2018). The surveyed farmers confirmed this when they stated that Lepidopteran order insects, namely, pod borer complex *Maruca vitrata*, *Helicoverpa armigera* etc., caterpillars and armyworm, as well as major sucking pests are the most damaging types of insects to lablab. This was further verified by the farmers when they reported that the timing and application of insect control usually occurs at least twice: once at flowering stage and second at pod forming stage, with third and fourth applications not uncommon.

The limited capacity in general by smallholder farmers to use pesticides (Njarui et al., 2004) makes the situation critical for needing solutions other than chemicals. All respondents in the current study mentioned that lablab left unsprayed by pesticide will either suffer yield losses or total crop loss by insects. However, the farmers mentioned the high cost of pesticides and insect damage as some of the most constraining factors for growing lablab.

To the farmers, the economic cost of not using chemicals is greater than using them, since crop failure is certain when lablab is left unsprayed. Yet, it has been shown that in some developing countries the long-term net benefits of using harmful pesticides are negative when the cost of lost labour and productivity caused by illness from chemicals are weighed against the savings from reducing loss by insect damage (Pingali et al., 1994). However, the socio-economic realities, such as providing food for today, facing smallholder farmers means that they often cannot think beyond today, let alone the long-term.

It is unsustainable that lablab production, or any other food production for that matter, hinges on whether it is sprayed or not. This highlights the importance of developing improved varieties through accession selection with tolerance or resistance to damaging insects. This, along with future breeding efforts will be an important part of an IPM strategy and will ultimately lead towards reducing insecticide use.

What are the strategies that farmers use to control insect pests?

Most interviewed farmers, with the frequency of 85%, revealed they use chemicals to control insects. However, they only use chemicals when absolutely necessary (they can’t afford to do otherwise) and many use them in conjunction with other pest control methods. Some of the surveyed farmers even mentioned they do not spray any chemicals whatsoever. This could mean that their alternative control methods work well enough to not warrant chemical use or that they can't afford chemicals or simply that they are just poor farmers. The first reason is probably the most likely. Traditional methods used by smallholder farmers are important parts of their insect control strategies (Francis et al., 1978). The survey revealed that these methods included using diverse polycultures, biological control agents, ashes and perimeters of insect-deterring neem trees. Some even reported they use a strategy called 'mahande' which is a natural insect control used by elders. Finally, the accessions they are using are locally adapted to the inhospitable environments they are being grown in through millennia of evolution against harmful insect pests and diseases. These accessions are the best suited for using as germplasm to develop more insect resistant cultivars.

Are there genetic variations among lablab accessions in their susceptibility to identified major insect pests?

The current study evaluated the relative insect infestation level of different accessions but did not designate any accessions to be labelled as 'resistant' or not. Furthermore, insect damage to plant parts was not assessed; however, the assumption was made that if insect infestation is high, then the level of damage would also be correlated in the same direction.

Based on the results in the current study, there were significant differences in infestation levels among accessions for all the major insect species including thrips, aphids, pod sucking bugs and pod borers. However, the UNIANOVA model used to generate these results included all of the highly variable accession time to 50% flowering data and was not split into different maturity groups. These results show there is a great deal of genetic variation among the accessions involved in the study. However, this also means that the results should be taken with caution since there were many variables that could have affected the significance levels such as different time to 50% flowering and intercrop or sole crop. More complex models were attempted in the analysis of the data but were not used. One, for example, was including time to 50% flowering as a covariant, but there was no one model that improved the results more than what was used in the current study.

Notwithstanding, in general, these results correspond to the results from Naik and Patil (2009) and later by Prasad (2014), when they found resistance in some lablab accessions to pod borers (they studied damage by pod borer *Adisura atkinsoni* and infestation levels of unspecified species of pod borers respectively). Mondal et al. (2017) found that one lablab variety from India was significantly more resistant to aphid infestation than the susceptible variety. However, these researchers conducted their studies in Asia with Asian origin accessions and the current study evaluated lablab accessions mostly with East African origins which means that results should only be used as comparison, not for confirmation of resistance. Furthermore, in the current study, the high variation in time to 50% flowering, possible insect sampling error and insecticide use may have caused confounding factors affecting the results. Therefore, it is difficult to say with certainty the variation in insect infestation levels was caused by genetic resistance.

Insecticide use and errors in insect sampling are some other variables that could have affected the results in the current study. The trial was sprayed with chemical insecticide at critical times in order to obtain reliable yield data; therefore as a result, insect populations decreased immediately following the applications. While this situation is not ideal, the defence can be made that the whole experiment was treated uniformly leading to relatively similar patterns of insect presence across all accessions. Another reason the data may be valid despite the chemical insecticide usage is the sampling period had many sampling dates, spread out over a relatively long time period over the season. This means that the opportunity to get reliable data, following a chemical application once the insects have been able to regenerate was still possible. Presumably the insect counts would have regenerated and occurred relative to an accession following insecticide application leading to similar results had there been no insecticide usage.

When insect sampling, all personnel followed a standardized protocol, but several different people took counts, each sampling a separate block, thus leading to possible count differences among blocks. There was a significant sole crop/intercrop*block ($P<0.004$) interaction in pod borer counts where all three blocks showed dramatically different patterns suggesting that either a sampling error occurred or that there was just a natural field effect causing unexplainable differences. An error that was known to have occurred for certain was that all damaging beetles, including blister beetles (*Mylabris* subsp.) were mistakenly grouped in with the pod sucking bugs causing inaccuracies and explaining why the pod sucking bug numbers were so high late in the season.

Whether an accession that has a potentially short or long growth cycle is more beneficial for avoiding insect attacks is not known since there is little data available from other studies. The accessions in the current study expressed significant variability in time to 50% flowering which is expected considering the phenological plasticity and diversity of traits characteristic in lablab accessions (Karachi, 1987; Maass, 2016). The different length in growth period among accessions might have had an effect on insect infestation levels considering the correlation between higher insect attacks at the timing of the plants' attractive reproductive stage. In a perfect world, all accessions would have had the same flowering period, thus eliminating this variable and allowing us to see if differences were more about genetics rather than phenotypic differences. However, this was not the case and if they all flowered simultaneously, discovering potentially valuable differences, for instance insect avoidance by early or late maturity, would not have been possible. The results showed weak trends towards higher infestation levels in earlier maturing accessions rather than in later maturing accessions across all the insect species but this was especially evident in the pod borers. However, these trends were in contrast to Regupathy et al. (1970) who found more resistance to pod borer in early maturing lablab accessions. The correlation in the current study may have been caused by 1) seasonal differences, for example, higher humidity early in the season from the rainy season causing potentially higher populations and higher feeding activity (Sambathkumar et al., 2017); or 2) The chemical applications began only after the first accessions had started to flower. This resulted in insect counts being taken on early flowering accessions before chemical applications and thus no insect death from chemicals. This is compared to counts starting on later flowering accessions after chemical insecticide applications took place and the resulting insect death occurrence. This possibly caused lower insect counts for later flowering accessions compared to earlier flowering accessions due to chemical control.

Grouping accessions by relative time to 50% flowering

An accession may be either advantaged or disadvantaged to others depending on its 50% time to flowering relative to the insect populations at this time. For this reason, each accession was grouped into early, medium and late based on their sole crop mean time to 50% flowering. Insect count data was compared to accessions only from within the same group. This was an attempt to reduce the high variability among the diverse set of accessions. There were still large differences among the accessions' time to flowering within the groups, so it did not eliminate this variable completely. Plant maturity can help determine which insects are present because thrips and aphids generally feed on plant parts, such as growth points, stems, leaves and flower buds, while pod borers and sucking bugs tend to feed more on larger plants at their reproductive stages (Abate and Ampofo, 1996). Therefore, in the early season, when all plants are in the seedling stage, differences in maturity may not have affected counts of thrips and aphids to the same extent as the other insect species.

When the accessions were grouped based on time to flowering there was significant variation in thrip infestation levels among accessions in the early flowering group. Based on thrip count data there were far higher thrip counts in the early part of the season than later in the season. This allowed for counts in early maturing types to reveal accessions that were more susceptible to infestations. Two accessions in the early group rated very high for resistance to thrip infestation. The differences could have been caused by genetic traits such as chemicals causing a repellant or could have been due to non-genetic factors. With respect to the pod borers from the late flowering group, there were significant differences between accessions. There was no correlation with time to flowering and insect infestation levels. Within this group, two accessions had zero counted pod borers and therefore should be considered for further testing or breeding. The differences in pod borer counts may be explained by accessions having differences in leaf nutritional quality, which is an indicator of efficient food utilization affecting larval growth and survival (Sambathkumar et al., 2017).

Intercrop versus sole crop

There is little literature on insect infestations involving lablab and maize. However, there is evidence to support intercropping other legumes and maize to reduce insect damage. A study in sub-Saharan Africa by Amoako-Atta et al. (1983) found significantly reduced pod damage by pod borer *Maruca testualis* in mixed cowpea-maize-sorgum crop compared to sole cowpea. Kyamanywa et al. (1993) found that intercropping maize and cowpea significantly reduced thrip infestation with the possible reason of thrips preferring open areas rather than closed-in areas present in an intercrop environment.

The results in the current study showed that intercropping significantly reduced insect infestations in two out of the four sampled insect species when compared to sole cropping. When lablab was intercropped with maize there were significantly fewer thrips (means of 23.8 thrips in sole crop compared to 6.3 thrips in intercrop). Perhaps the thrips preferred to avoid the inhospitable environment of the intercrop caused by higher humidity and temperature. This is in agreement to some farmers who, when interviewed, stated that intercropping reduces insect damage; however, there were more farmers that said they do not think that intercropping reduces insect damage. It is possible that the timing of each respective crop's establishment in the intercrop situation affects the degree to which intercropping reduces insect damage. The authors Pitan and Odebiyi (2001) reported that when planting cowpea 12 weeks after maize, damage by thrips was significantly reduced.

There were also significantly fewer pod sucking bugs counted (means of 17.6 sucking bugs in sole crop and 8.6 sucking bugs in intercrop) in the intercrop compared to sole crop. Pitan and Odebiyi (2001), reported that the effects of companion cropping, (where two crops are grown alongside each other) can reduce pod sucking bug damage by modifying the insect's habitat and interfering with its ability to recognize and seek out the host. Changes to the cropping system, such as from sole to intercropping, that result in pest population reductions, are cultural control methods creating an "association resistance" (Pitan and Odebiyi 2001). These practices are already commonplace in Africa.

However, the lower insect counts in the intercrop may be explained by dynamics such as inter-species competition. Miller et al. (2018) found that when lablab was intercropped with maize, plant growth was significantly less compared to sole lablab. Growth is suppressed for the legume in intercropping due to fewer resources such as light. The presence of smaller plants in an intercrop potentially lowers the capacity to host insects since there are fewer shoots, flowers and pods for insects to feed on.
In the current study, intercropping lablab and maize significantly delayed the time 50% flowering in lablab. This delay meant smaller plants and fewer open flowers in the intercrop lablab, compared to nearby sole lablab plots. In this situation, the insects may have skipped over the intercropped lablab and collected in the sole crop where more food was readily available. Furthermore, host plant concentrations, meaning food supply, can change the potential number of generations of insects such as the pod borer African Bollworm (*Helicoverpa armigera)* from two to eight (Abate and Ampofo, 1996). This type of interaction may possibly explain why there were higher pod sucking bug counts over the sampling period in sole cropped lablab.

Altieri et al. (1978), suggested that traditional cropping, such as the system often practiced in sub-Saharan Africa, can reduce insect damage. However, when most farmers in the region already involve these types of systems, and still have to use chemicals and suffer great yield losses, it is difficult to tell a farmer there are no other options. This is why further research is needed on evaluating accessions native to East Africa for genetic resistance to pests. Breeding improvements can take advantage of the high genetic variability of lablab but should also incorporate the traits that are of economic importance (Prasad et al., 2015), such as palatability. More work is also needed to determine if early or late season maturity is better for avoiding pests and what type of intercropping patterns (such as timing of establishment relative to the other crop) reduces insect pest populations. Finally, a management package that is disseminated to farmers to go along with improved varieties is required and should be undertaken by many actors including researchers, agronomists, NGOs, extension officers and private agriculture input companies.

6.2 Socio-economic study

The majority of famers involved in the survey were very experienced and already had a history of growing lablab. More than half of them said that their parents used to grow the crop, which means they have some existing traditional knowledge. They were able to renew some of their lost knowledge when they received access to training as part of the participatory on-farm study. They were also able to gain access to improved accessions which they can keep and share with their neighbours. These farmers represent voluntary innovators and will likely lead the direction of farming in their respective areas. For example, if a neighbour sees them making a profit from growing lablab, then there will be further adoption of legumes into the system (Odendo et al., 2011). A small amount of participatory research in a community can have a large impact.

There are drawbacks however, to using a pre-existing group that is already involved with local research. For one thing, it is hard to separate out what their practices would be if there were no outside influences from an ongoing study. It is important to know what farmers would do without input from researchers in order to gain a clear picture of what is happening in the larger community. Perhaps surveying a control group of non-lablab growers, or at least farmers not already involved in the lablab participatory research, would have allowed for more representative results.

One of the limitations of a questionnaire with answers already listed is that the responses are not blind and can therefore be biased. In hindsight, the respondents should have been given the freedom to answer questions such as, "What are the reasons or constraints for growing lablab?" without being restricted to pre-listed answers. However, the method was chosen for the current study in order to generate a range of standardized answers that could be easily ranked.

What are current experiences and expectations of a group of farmers with growing, using and selling lablab in northern Tanzania?

The results of the survey showed that the main reasons farmers grow lablab are for income generation, household food, drought tolerance, fodder and soil cover. However, the number one reason they said they grow lablab is to sell it for cash while the number one constraint is a poor market or price. It seems the decision to grow lablab or not is based on a market dichotomy; when the price is good there will be production, and when the price is poor there will be less production. These results are similar to Ndove et al. (2004) where they found that smallholder farmers recognize the importance of profit as their main goal after feeding themselves, but they see that profit only comes when input costs are lower than sales revenue.

In general, legumes generate two to four times the price as maize in sub-Saharan Africa (Rao and Mathuva, 2000). These authors go on to say that because legumes are easily marketed, they are attractive cash crops. This view is similar to the results found in the current study where farmers responded they can usually get a higher price for lablab than for any other crop they grow on the farm. They also indicated they can almost always market their lablab. The fact that markets are shifting towards becoming more open with fewer governmental tariffs (Jones et al., 2002) is good news for new marketing opportunities of lablab whose price is largely tied to demand from Kenya. Perhaps export markets beyond Kenya are possible. This was the case recently where pigeon peas were being processed in Tanzania and then the product was being exported to Europe and Asia (Jones et al., 2002).

Farmers expressed a number of their main constraints in growing lablab, other than pesticide and insect issues which are addressed in the other section of the discussion. These constraints include poor marketability, weather variability, poor varieties, lack of seed and problems with weeds. While lablab is considered drought tolerant compared to common bean (Maass, 2010), it is still susceptible to extreme weather. If a long-maturing variety is used and rainfall is limited, the crop will continue to grow and produce flowers indeterminately causing seed yield – the fraction used most often for cash income – to be low (Whitbread et al., 2011). The ‘poor varieties’ that farmers are referring to are those that take too long to mature and also have disease problems. Therefore, research on developing shorter-maturing varieties to avoid drought periods is needed since lablab does not require much rain once it is established, due to its long roots.

Do the farmers perceive lablab as an important crop for their livelihood and a beneficial component of their farming system?

Lablab is an important component of intercropping systems with maize (Hill et al., 2006; Kimani et al., 2012) and sole cropping in drought-prone areas (Miller et al., 2018). The current study found that farmers rely on lablab heavily as it is a large part of their farming system. Most farmers grow it as an intercrop with other crops on their farm due to the necessity of providing both food and a cash crop on the same land parcel. The farmers stated they are using lablab on average in almost half of their land base (46%). This research demonstrates the confidence they have in lablab to provide the needed functions. This is not proof that it will work for every farmer, but it is support of its potential. Farmers ranked drought tolerance as the third main reason to grow lablab. This was especially demonstrated by farmers in Hedaru, Kilimanjaro region who stated that it is one of the only “cash” crops that they can grow in the area because it is so dry. The drought-tolerant qualities of lablab fit in well towards the goal of adopting practices for climate-smart agriculture in Tanzania (CIAT; World Bank, 2017).

Adoption of lablab and the socio-ecological niche

What are the factors that determine if a legume practice will work in an area or not? Adoption depends on many socio-economic, cultural and biophysical factors. One single type of legume-based practice will not work for all farmers. Adoption is based on the farmers' needs and abilities within their existing situation. The role of the researcher should be to help identify suitable niches the legumes will fit into and to limit the constraints for adoption of legume technologies. Solutions from agronomy or marketing alone will not enable increased production of sustainable practices. The solution will come from multifaceted approaches from incorporating research and extension of many different disciplines together.

Lablab multifunctionality and viability for smallholder Tanzanian farmers

The literature has stated that lablab is a crop with many functions that are each valuable for smallholder farmers (e.g. Whitbread et al., 2011; Maass et al., 2010). The findings of this study are similar as it displays that farmers see the importance of lablab's having multifunctional uses. However, for there to be increased lablab production and thus to be a viable enterprise for smallholder farmers the crop must be profitable. Accessions need to be improved to become more palatable to improve marketability and be more insect resistant to reduce production costs. Then the improved seeds need to be made available to farmers. Farmers won't just grow lablab to improve the soil, there must also be an added income generation. Perhaps farmers will choose lablab over other crops due to its multifunctionality because it is worth more than maize or common bean while being drought tolerant and also a soil improver.

7. Conclusion and recommendations

This study used farmer interviews and a field trial for determining if lablab is a multifunctional and viable crop for farmers in the region of northern Tanzania. We asked a group of lablab farmers about their perceptions, traditional knowledge and production practices of lablab. It was found that farmers rely on lablab for multiple functions and chief among those is income generation. Farmers also use lablab for household food consumption, animal fodder, soil cover and drought-tolerance. Lablab can be economically viable when certain measures are met, such as favourable grain prices and the reduction in costly and harmful pesticide usage. The field study revealed the potential of genetic sources for insect pest resistance, and that intercropping lablab and maize can be an important management practice to reduce insect pest damage.

Determining the most important socio-ecological constraints and making recommendations towards increasing the uptake of an improved legume-based practice such as growing lablab was a goal of this study. Lablab is an alternative crop that can help make a smallholder farming system more resilient to pressures such as climate change. The findings gathered in this thesis will hopefully make a difference towards a better understanding of the crop and contribute to the development of lablab for helping farmers improve their livelihoods.

In view of the findings, several recommendations can be made:

- Most crop research and development efforts worldwide involve only a handful of different species. Indigenous crops represent an important opportunity to stave off a world food crisis and more efforts should be focused on researching and developing these so called ‘forgotten crops’ and making them available to farmers.

- Farmers mentioned a poor market or selling price as their number one constraint when it comes to growing lablab. Therefore, farmers need help with marketing their product. This could come in the form of value-addition for lablab by adding new processing and packaging facilities. Another opportunity is to develop a market for a grain that people want to eat locally. This will hopefully result in releasing farmers from the Kenyan market that is currently determining the price.

- A multi-disciplinary approach should be incorporated into developing crop varieties that are agronomically sound for farmers but also meet the preferences of the consumer. This could be achieved by linking researchers directly with marketing firms who can work together towards solving the problems. In the case of lablab, it would be about developing varieties that are insect-resistant and have improved marketability from improved palatability.

- More participatory research should be conducted in Tanzania. Studies involving farmer-to-researcher participation (see Kerr et al., 2007) have shown there is a direct link between on-farm research and increased adoption of legume-based practices.

- In order for farmers to gain higher profit margins, they should receive training in how to form cooperatives. Cooperatives represent a way for them to band together in a community which could lead to lower shipping costs and better market information. They could arrange less costly transport for their product by cutting out the middle trader and shipping in bulk directly to the foreign buyers. Most famers cited that lack of education and training was the reason they do not currently form cooperatives.

8. References

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9. Appendix

Appendix 1

Structured interview guide

SURVEY ON THE FARMER'S KNOWLEDGE and PERCEPTIONS OF AGRICULTURE [LABLAB (*Lablab purpureus* (L.) Sweet)] PRODUCTION IN A SELECTED AREA IN TANZANIA

MAIN QUESTIONNAIRE

Prior to interview state: I am conducting a survey to investigate farmer's knowledge and perceptions of Agricultural [of Lablab] production as part of a master's thesis.
Your input is very important to this study and improving agriculture and all answers are confidential.

Respondent number:
Respondent name (confidential):
Mobile number (confidential):
Location (Region, District, Tarafa, Kata, Village):
Date:
Start time: **End time:**

Local names of Lablab: Ngwara, Mmba, Hyacinth bean

1. Which age category do you belong to*? (Don't need to ask just circle one).*
    a. 15-25
    b. 26-40
    c. 41-60
    d. 61 and above

2. Are you male or female? *(Don't need to ask just circle one).*

3. Number of family members in your household?

4. How many years farming experience have you had?

5. What is your total farm size in acres?

6. How many people help on your farm including family members and paid workers?

7. Is the farm the sole means of family income?

8. Which kinds of crops (grain legumes, cereals, fruits, vegetables) did you cultivate last (2017) year? Why do you grow them?

Crop type (including intercrop)	Area/crop (ha)	Yield (Kg or bag) weight/kg	Reason? How many bags are consumed vs. sold	Expenditure per year 1 ac (tsh)	Return/ selling price/bag (tsh)

9. What is your current crop rotation (what crops and why)? *Or alternative: Which crops have you grown on the same field/area for each of the past 4 years?*

Field	2018	2017	2016	2015	2014
One					
Two					

10. In which months do you plant, weed, provide insect control, and harvest Lablab?

Activity	J	F	M	A	M	J	J	A	S	O	N	D
Planting												
Weeding												
Insect control												
Harvest												

11. Which crops did you grow in the past and why did you stop growing them?

12. For how many years have you been growing Lablab? Did your parents or their parents grow this crop? Follow-up questions: *Did your grandparents grow lablab too? How many insect pests did they have and what scale of production (larger fields or around house) did they have?*

13. Please 10 place beans accordingly in the boxes beside the reason why you grow Lablab. Place more beans in the boxes where the reason to grow Lablab is more important and less beans in the boxes beside the less important reasons.

Reason to grow Lablab	Place 10 beans below in the boxes
Household food crop (Chakula cha nyumbani)	
Drought tolerance (Uvumiliau wa ukame)	
Sell for money (Kwa ajili ya kuuza)	
Soil cover (Kwa ajili ya matandazo)	
Fodder crop (Malisho ya mifugo)	
Other (list e.g. Medicine, Soil health? Rotation? Weed control? Etc.) (Vinginevyo mengineo)	

14. Please 10 place beans accordingly in the boxes beside the major constraints (changamoto) or challenges for growing Lablab. Place more beans in the boxes where the constraint to grow Lablab is more important and less beans in the boxes beside the less important reasons.

Constraint to grow lablab	Place 10 beans below in the boxes
Poor Lablab varieties/low yield	
Lack of seed availability	
Weed problems	
Weather or climate	
Availability or cost of inputs or (e.g. seed, chemicals, fertilizer	
Insect problems	
Poor selling price/poor market	
Other (list e.g. poor yield, rotation, mechanization etc.)	

15. How often does your family eat Lablab? Grain or vegetable?

16. What are the nutritional benefits that Lablab provides?

17. Which kind of insects are most damaging for growing Lablab (get local name, Kiswahili name and English name)?

18. What methods of insect control do you use for Lablab? What are the stages of Lablab for control? How effective are they? If no insecticide is applied what is the likely consequence?

19. Other than insecticide, what methods of insect control do you think would be effective?

20. What variety of Lablab do you grow? *Follow-up question: If it's black ask if it has another name.*

21. How could Lablab varieties be improved?

22. Where do you get your seed? E.g. *Neighbor/other farmer? Keep own? Agricultural Supplier?*

23. Does intercropping Lablab and maize or other crops reduce insect damage? If yes why?

24. How do you access information and knowledge about how to grow Lablab (e.g. local authorities, associations, other farmers, seed suppliers, ag. suppliers, researchers)? *Follow-up question: Who taught you how to grow lablab?*

25. Can you sell your Lablab each year?

26. Compared to other crops you grow does Lablab provide more or less income? Provides lower income compared to onion.

27. Do you remember the price you sold Lablab for in the last 3 years on the market (TSh)? *Or if they don't remember then can ask if price has either increased or decreased?*

28. Where do you sell your Lablab?

29. Do you form cooperatives (Chama cha Ushirika) with other farmers to your crops?

30. Do you expect to grow more Lablab in the future on your farm? Why or why not?