FACULTEIT INDUSTRIËLE
INGENIEURSWETENSCHAPPEN

CAMPUS GEEL

Stingless Bees as an Opportunity for Sustainable Development in Northern Tanzania

Foraging Potential in Agroforestry Homegardens

Robin TERSAGO

Promotor: Prof. Dr. Ir. Karen Vancampenhout (KU Leuven)

Copromotor: *Prof. Dr. Didas Kimaro (MWECAU)*

Supervisor: Oforo Didas Kimaro (MWECAU/KU Leuven/TU Dresden)

Masterproef ingediend tot het behalen van de graad van Master of Science in de Biowetenschappen: *Land- en tuinbouwkunde, optie Toegepaste omgevingswetenschappen*

Academiejaar 2021-2022

Acknowledgements

This thesis has been the joint effort of many different people who have helped me along the way. Conducting research in an environment like the Northern mountainous landscapes of Tanzania was no easy feat and it has left me thankful to many people.

First, I would like to thank Prof. Kimaro and Mr. Oforo. I have felt right at home from the start of my stay, and this was largely due to your great hospitality. You have guided me through often unknown terrain by giving me the perfect balance between keeping me safe and letting me explore on my own. I would also like to thank Dr. Mbwambo of TAFORI and Dr. Mwango of TARI Mlingano for helping me with various practical challenges and accompanying us along the way.

In addition, I would like to thank Prof. Vancampenhout for helping me with every bump in the road that I encountered before and after I went to Tanzania.

I would like to thank VLIR-UOS for providing me with the opportunity of doing research in Tanzania and funding part of this research.

Next, I would like to thank all the friends I have made during my stay in Tanzania, especially at MWECAU society, Father Charles and Father Peter. You made sure we stayed in a wonderful place and provided me with experiences I will never forget.

I would also like to thank my housemates of my student home in Geel who were always there to help and support me during my studies. Ward deserves a special mention for helping me with the practical elaboration of the smartphone application.

Further, I would like to thank all the smallholder farmers who were kind enough to let me interview you. Even though the language barrier was large at times, you have taught me to enjoy life more simply every now and then.

I would also like to thank all my family and friends for supporting me during my studies and during the writing of this thesis.

Additionally, I want to thank my parents and my sister for always listening to my talks about stingless bees and my anecdotes about life in Tanzania. I especially want to thank my dad for going through my thesis many times and providing me with valuable feedback.

Lastly, I want to thank Nele for the countless laughs we had in Tanzania, but also more importantly for the continuous support during the field work and every time when I needed it most.

Samenvatting

Ontbossing is een groot probleem voor de Eastern Arc mountains, één van de globale biodiversiteitshotspots. Een snelle bevolkingstoename en andere economische en milieu-uitdagingen hebben deze regio geconfronteerd met deze bedreiging. Om dit te bestrijden moet de inheemse vegetatie in stand worden gehouden. Angelloze imkerij is een activiteit die veel potentieel heeft om als stimulans hiervoor te dienen. Bovendien kan het een extra bron van inkomsten vormen voor kleinschalige boeren. Angelloze imkerij kent trouwens een rijke geschiedenis in Oost-Afrika, maar heeft recent aandacht verloren ten gunste van stekende bijen.

Bijgevolg wordt angelloze imkerij in Afrika slechts zeer zelden beschreven in de wetenschappelijke literatuur. Dat is een gemiste kans, want het kan op meerdere vlakken bijdragen tot de Duurzame Ontwikkelingsdoelstellingen. Zo vergt het houden van angelloze bijen niet veel inspanning en kan het dicht bij huis worden beoefend. Op die manier kan het dienen als een inkomstenbron voor traditioneel kwetsbare groepen zoals eenoudergezinnen en gezinnen met een gehandicapt lid. Bijgevolg draagt het bij door de arbeidskansen voor vrouwen te verbeteren (SDG 5) en een extra bron van inkomsten te genereren voor kwetsbare gezinnen (SDG1 en SDG10).

Deze thesis dient als een verkenningsstudie voor het houden van angelloze bijen in de agroforestry homegarden systemen van Noord-Tanzania. Naast de basiskenmerken van de angelloze imkerij, werd vooral aandacht besteed aan het foerageergedrag van angelloze bijen in agroforestry homegardens. Deze analyse is een belangrijke stap in de optimalisatie van de samenstelling van de homegarden voor angelloze bijen. Honingstalen werden ook geanalyseerd om het stuifmeel erin te identificeren. Dit leidde tot een beter inzicht in het verband tussen angelloze bijen en de vegetatie van de homegarden. Ten slotte werd een smartphone-applicatie ontwikkeld om kleinschalige boeren te helpen om beter geïnformeerde beslissingen te nemen bij de keuze van planten voor hun homegarden.

De resultaten toonden aan dat het houden van angelloze bijen veel potentieel heeft als stimulans voor het behoud van inheemse vegetatie en als inkomstenbron voor kleine boeren. Het vergt weinig inspanning dicht bij huis en levert de imkers een extra inkomen op. Er is echter ook gebleken dat angelloze imkerij nog voor vele uitdagingen staat. Sommigen zijn praktisch zoals het vinden van een betere manier om de angelloze bijen tegen roofdieren te beschermen, maar de belangrijkste uitdagingen zijn structureel. Het grootste deel van deze structurele problemen zijn te wijten aan een gebrek aan kennis en opleiding. Het eerste gebrek kan worden opgelost door plaatselijke coöperaties op te richten of voorlichters van de overheid in dienst te nemen, terwijl het tweede kan worden opgelost door aspirant-imkers een opleiding te geven door meer ervaren leden van de gemeenschap. Deze ervaren leden moeten ondersteund worden om hun kennis te delen en andere bijenhouders te helpen, bijvoorbeeld door hen te helpen bij het splitsen van een kolonie.

Aangezien deze thesis slechts het begin is van onderzoek naar het houden van angelloze bijen in Tanzania, zijn er meer vragen dan antwoorden gegenereerd en is het potentieel voor verder onderzoek enorm. Het is echter duidelijk dat het houden van angelloze bijen een groot potentieel heeft voor natuurbehoud, inclusie en het genereren van inkomsten.

Sleutelwoorden: Duurzaamheid, Angelloze imkerij, Foerageren, Agroforestry, Tanzania

Abstract

Deforestation is a major threat to the Eastern Arc mountains, one of the biodiversity hotspots of the world. A rapid increase in population and other economic and environmental challenges have led this region to face this problem. To combat this, indigenous vegetation should be conserved. Stingless beekeeping is an activity which has great potential to serve as an incentive for this. In addition, it can provide an additional income source to smallholder farmers. It possesses a rich history in Eastern Africa but has recently lost attention in favour of stinging beekeeping.

Consequently, stingless beekeeping in Africa is only very rarely described in scientific literature. This is a missed opportunity since it can contribute to the Sustainable Development Goals in multiple areas. As stingless beekeeping does not require much effort and is possible to practice close to a home, it can serve as an income stream for traditionally vulnerable groups such as one-parent families and families with a disabled member. Therefore, it contributes through improving work opportunities for women (SDG 5) and providing vulnerable families with an additional source of income (SDG1 and SDG10).

This thesis serves as a reconnaissance study for stingless beekeeping in the agroforestry homegarden systems of Northern Tanzania. In addition to basic characteristics of stingless beekeeping, foraging in the agroforestry homegardens was a particular focus. Analysing the forage of the bees is a major step in optimising the composition of the homegardens for the bees. Honey samples were analysed to identify the pollen inside, which led to a better understanding of the link between stingless bees and the vegetation of the homegardens. Finally, a smartphone application was developed to help smallholder farmers make better informed decisions on which plants to choose when arranging their homegarden.

The results showed that stingless beekeeping has undeniable potential as an incentive for conserving indigenous vegetation and as an income stream for smallholder farmers. It requires very low effort close to home and provides the beekeepers with an additional income. However, it also showed that stingless beekeeping still faces many challenges. Practical issues include finding a better way to protect the stingless bees against predators, but the main problems are structural. Most of these structural issues are due to a lack of awareness and a lack of training. The former of which can be solved by forming local cooperatives or employing government extension officers, while the latter can be solved by providing aspiring beekeepers with training from more experienced members of the community. These experienced members should be empowered to share their knowledge and help other beekeepers, for example by helping them to split a colony.

As this thesis is only the start of research on stingless beekeeping in Tanzania, more questions than answers were generated and potential for further research is huge. However, it is clear how stingless beekeeping has great potential for conservation, inclusion, and revenue generation.

Keywords: Sustainability, Stingless beekeeping, Foraging, Agroforestry, Tanzania

CONTENTS

List of symbols

List of abbreviations

a.s.l: above sea level

AGF: Agroforestry

SDG: Sustainable Development Goal

TBS: Tanzanian Bureau of Standards

Tsh: Tanzanian shilling

USD: United States Dollar

List of figures

List of tables

Introduction

Deforestation is a major problem for the Eastern Arc Mountains of Tanzania (Hall et al., 2009). It is a region which has been internationally praised for its rich biodiversity. But as a result of increased population pressure in combination with economic and environmental challenges, it faces many problems correlated to deforestation (Brooks et al., 2002; Buchanan et al., 2011; Butz, 2013; Myers et al., 2000). The Tanzanian government has identified beekeeping as one of the industries that suffer most under deforestation. Consequently, 'The Tanzanian National Beekeeping Programme' was established (Bradbear, 2009).

However, beekeeping could also be part of the solution, as it can provide an incentive to keep many of the indigenous trees. People can make a profit from the honey production and turn the trees and shrubs into an asset as forage for the bees (Macharia et al., 2007; Sinyangwe et al., 2010). The activity has a long history in the region and was first recorded by Smith (1958) during British colonial times. It has since evolved and now employs 2 million people and is a 19 million USD industry which makes Tanzania the second largest producer of honey in Africa, second only to Ethiopia (Tutuba & Vanhaverbeke, 2018). The local tradition of beekeeping also has potential in the agroforestry homegarden systems. However, a recent study by Wagner et al. (2019) found that the defensive stinging behaviour of the local *Apis melliferata* has led many farmers, even children of beekeepers, to abandon the local tradition of beekeeping. In addition, farmers in Northern Tanzania indicate that the lack of involvement for women and children due to the defensive stinging behaviour of the bees is a disadvantage of honeybee beekeeping (Tutuba & Vanhaverbeke, 2018).

Those disadvantages are mitigated by stingless beekeeping or meliponiculture. The stingless bees are still able to produce honey and their lack of a functional stinger makes them safer to handle (Mustafa et al., 2018). It is especially promising for vulnerable families like one-parent families or families with a disabled member because stingless beekeeping does not require much time or work (Slaa et al., 2000; Wagner et al., 2019). Consequently, stingless beekeeping contributes to the sustainable development goals through providing vulnerable families with a supplementary source of income (SDG 1 and SDG 10) and improving work opportunities for women (SDG 5) (United Nations, 2015).

Meliponiculture in Northern Tanzania still faces many challenges before it can be a genuine addition to the livelihood of farmers in the region (Tutuba & Vanhaverbeke, 2018). These challenges include awareness, proper training, and the lack of an organised market. One of the basic necessities for beekeepers is a floral calendar which summarizes the flowering times of important plants for the bees. However, it has not been made yet for African stingless bees (Bradbear, 2009). This floral calendar would help farmers to make informed decisions on how to improve the suitability of their homegarden for stingless beekeeping. In addition, it will help to investigate if other regions are also appropriate for stingless beekeeping

Sources about foraging behaviour by stingless bees, but also about stingless bees in general are mostly written on neotropical species. Consequently, articles about African stingless bee species are scarce. One of the articles which mentions African stingless bee species is a book describing stingless bees by Vit et al. (2013). That makes it useful for general parts of the study, but it lacks the regional specificity of Northern Tanzania stingless beekeeping.

In the area of stingless beekeeping in Eastern Africa, a lot of work remains to be done. It is seen as an alternative source of income that has exciting potential but due to a lack of awareness and knowledge, it is still a rare and regional occurrence to see stingless bees being kept. Farmers have built up a lot of indigenous knowledge on stingless beekeeping over the years, but it has not been documented in scientific literature.

This study will try to contribute to this knowledge by providing a general overview of stingless beekeeping in the area through conducting surveys with farmers who are practicing it. During those surveys, the focus will mostly be on the ecosystem services provided. For stingless bees, that mostly consists of two services being pollination and honey production. A floral calendar will be made to help farmers make better informed decisions on which plants to use in their homegarden. The floral calendar will also help researchers compare different landscapes to each other to check the suitability of the environment for stingless beekeeping in terms of forage availability. The data used for making this tool will be a combination of information provided by the farmers, scientific literature, and a pollen analysis of the honey. This floral calendar will be made into an application which visually represents the number of flowering plants at every month of the year. A next step in the popularisation of stingless beekeeping in the region would be quality assurance, enabling farmers to sell it on a larger scale and even export it. This is one of the many interesting research opportunities which falls outside the scope of this study. Therefore, it is important to mention that this study provides only the starting point for research on meliponiculture. This study will try to reveal the management and potential of stingless beekeeping in Northern Tanzania.

Objectives

General objective

The general objective of this study is to perform a reconnaissance study on stingless beekeeping in Northern Tanzania as no study currently exists on this matter. Stingless beekeeping will be generally described, with a particular focus on foraging in the environment by the stingless bees.

Specific objectives

1. To qualify smallholder farmers practicing stingless beekeeping in the Northern mountainous landscapes of Tanzania
2. To describe the challenges and opportunities stingless beekeeping currently faces in Northern Tanzania.
3. To discover the forage sources used by stingless bees in an agroforestry homegarden environment
4. To make a decision-support app which can help smallholder farmers make informed decisions in the future

Research questions

1. What are the current stingless beekeeping practices in agroforestry systems of Northern Tanzania?
2. What information is needed to optimise choice of tree species in agroforestry system in space and time?
3. Can this be included in a decision support app?

1 AGROFORESTRY IN NORTHERN MOUNTAINOUS LANDSCAPES OF TANZANIA

1.1 Mt. Kilimanjaro

As the tallest free-standing mountain in the world and the tallest mountain in Africa, Mt. Kilimanjaro is an icon of Northern Tanzania and the greater region. The mountain consists of three peaks: Kibo, Mawenzi and Shira (Agrawala et al., 2003). Vegetation cover on Mt. Kilimanjaro is diverse and dependent on characteristics like humidity, pH, rainfall, altitude, and temperature (Friis & Lawesson, 1993). That diversity in vegetation can be characterised by zonation. These zones range from savanna in the lowest area through different types of forest to heathlands and eventually almost no vegetation on the highest slopes (Hemp, 2006b).

Figure 1.1: View of Mount Kilimanjaro from the foot slopes

One of these zones is the coffee-banana forests inhabited by the Chagga. This tribe has inhabited the mountain continuously for centuries (Sébastien, 2010). In the last few decades, the population has risen enormously with consequent high population densities in certain areas. In these areas, the Chagga use a unique type of land use called the Chagga homegardens. This type of agroforestry homegardens are maintained by local smallholder farmers as their main source of livelihood (Hemp, 2006a; Hemp & Hemp, 1999).

1.1.1 Structure and composition of homegardens

The main characteristic of Chagga agroforestry system on Mt. Kilimanjaro is their multi-layered structure. The most elaborate form of a Chagga system consists of four layers.

The top layer is a tree layer for the provision of wood, fodder, and shade. Under that layer, banana trees form the second layer. This second layer provides the shade necessary for growing coffee as a third layer. In recent years, this layer has mostly disappeared due to a crash in coffee prices. This will be further clarified in 1.1.2. The bottom layer is mostly used for the cultivation of smaller vegetables like beans and yams. However, not every layer is always present and their relative abundance as well as planting density varies between regions and individual homegardens (Hemp, 2006a). On the lower slopes of the mountain, the Chagga homegardens are not common and the main cropping system is maize cultivation in foothill farms (Ichinose et al., 2020).

Figure 1.2: Contemporary Chagga homegarden on Mt. Kilimanjaro with a top layer of trees, a banana layer, and a bottom layer of smaller vegetables. The bottom layer is not well visible because the banana trees block the view. As is most common nowadays, a coffee layer is not present in this homegarden

Most Chagga agroforestry systems in the Kilimanjaro region are of the coffee-banana type. This type is a very biodiverse system containing approximately 520 distinct species of vascular plants. Over 400 of these plants are non-cultivated. The latest synthesis about plants in a Chagga system has been compiled by Hemp (2006). That study found that forest species make up the majority (194) of the plants in the homegardens by number. Ruderal species are also common with 128 species inventoried, including some (41) neophytes.

Livestock such as cattle, goats, sheep, pigs and sometimes poultry are also an essential part of the Chagga agroforestry system. Many articles about the system such as Hemp (2006); Kitalyi et al. (2013) and Soini (2005) mention the role of beekeeping in the Chagga system as a source of additional income, but none provide more information on how it is practiced by the Chagga people and the challenges it faces.

1.1.2 Challenges and opportunities

Inhabitants of Mt. Kilimanjaro have faced many challenges throughout the years which have forced them to adapt their agricultural activities to new circumstances. These challenges have been institutional, demographic, social-cultural, political, technological, and infrastructural in nature (Misana et al., 2012).

Land scarcity has been one of the most important recent challenges faced by the inhabitants of Mt. Kilimanjaro. This relates to the inheritance of land by younger generations. The plot of one family must be divided between the sons of this family for them to inherit their own farming plot. This has made the plots too small to sustain a family and has led many younger generations to move to urban areas to practice activities not related to agriculture (Misana et al., 2012).

The shift away from the cultivation of coffee has been caused by several factors. These factors include damage to the crop by insects, but also the low coffee prices for export. That is due to a collapse in coffee prices between 1997 and 2005 (Ichinose et al., 2020; International Coffee Organization, 2018).

Replacing coffee, farmers have now shifted to other staple crops like maize and banana. Therefore, it forms an example of how farmers have shifted their source of income to accommodate external changes. This diversification combined with an intensification of the agricultural activities which are already present form the basis for gaining future sustainable livelihoods on the mountain (Ichinose et al., 2020).

1.2 South Pare mountains

The Pare mountains are part of the Eastern Arc Mountains, a geologically old mountain range that starts in Southern Kenya and stretches throughout Eastern Tanzania (Hall et al., 2009). This mountain range is an important area for biodiversity conservation, ranking among the top of global areas for endemic birds and plants (Burgess et al., 2007). The Eastern Arc Mountains comprise of two complexes in Northern Tanzania. These mountain complexes are the Pare mountains and the Usambara mountains. However, despite both being in the same mountain range, the Pare mountains have received less attention in scientific literature than the Usambara mountains (98 to 311 results on Web of Science). That makes the Pare mountains an interesting study site.

The Pare mountains themselves can be further subdivided into two mountain complexes, namely Northern Pare mountains, and Southern Pare mountains. The focus of this study is on the Southern Pare mountains. The mountains are largely inhabited by a tribe who call themselves the Asu, but they are known throughout Tanzania as the Pare people (von Hellermann, 2016).

Analogous to Mt. Kilimanjaro, the Pare mountains flourished during the 1940s through the sale of coffee from their agroforestry systems. The profits gained from coffee cultivation were mostly invested into education for younger generations which made the region highly educated. As on Mt. Kilimanjaro, the crash in coffee prices has also led the farmers in this region to abandon the crop and diversify their production (von Hellermann, 2016).

Diversification will be essential in the future to increase the resilience of the Pare people to climate change and an increased population pressure. In addition to this shift in cultivation of crops, beekeeping can be a part of this diversification (Charles et al., 2013). More specifically, stingless beekeeping is an income generating activity with enormous potential. Before explaining stingless bees in a context of beekeeping or meliponiculture in chapter 3, the focus of the next chapter will first be on stingless bees as a species on the African continent.

Figure 1.3: Agroforestry in the South Pare mountains. These agroforestry systems share their layered structure with the Chagga agroforestry systems on Mt. Kilimanjaro but are less dense

2 STINGLESS BEES IN AFRICA

Stingless bees (*Meliponini sp.)* are a remarkably diverse group compared to stinging honeybees (*Apini sp.*). They have branched off the evolution from the other bee and bumblebee species at an early stage. At that stage in time, the continents as we know them today did not yet split which explains their appearance throughout the tropics in various parts of the world. That early branch off also explains their different appearance from stinging honeybees which is mostly characterised by their inability to sting and smaller size (Crane, 1992). Phylogenetically, stingless bees are most related to bumblebees, but stingless bee colonies are sustained for multiple years by the same queen. That characteristic is similar to stinging bees, making their behaviour to be most comparable to stinging honeybees. However, stingless bees and honeybees still have many differences which will be discussed later in this chapter (Michener, 1974; Nunes et al., 2014).

2.1 Taxonomy

The latest, widely used synthesis on the state of the knowledge about African stingless bee taxonomy was based on the anatomy of workers and was provided by Eardley (2004). He found that there was little information available in museums and literature, while the bees themselves are relatively common in the wild (Eardley & Kwapong, 2013).

In Africa, the 19 species that are currently described in the article by Eardley (2004) comprise of six genera. Every known stingless bee species on the continent behaves socially. One of the genera robs pollen and nectar from other stingless bee nests, while the other five genera collect their own pollen and nectar. Eardley (2004) himself mentioned that his summary of stingless bee species is probably an underestimation. As taxonomy is usually the first aspect researched for a species which demonstrates how stingless bee research is still very limited (Eardley & Kwapong, 2013).

Some species are not differentiated easily purely based on their morphology and nesting site. The use of tools like molecular data and morphometrics could be a solution to that issue, making the identification of the species more robust and eliminating the need for skilled personnel. That new method has been applied for African stingless bees in Kenya by Ndungu et al. (2017) but it was not able to differentiate between all types of stingless bees. This makes it a good addition to the morphometrical approach but not a replacement.

Scientific literature on stingless bee species occurring in Tanzania is rare. The latest articles summarizing the species described in scientific literature were written by Hamisi (2016) and Njau et al. (2010). A study by Nkoba et al. (2012) was conducted in Western Kenya, but it complements the knowledge well. The most extensive of these studies is the one by Hamisi (2016) as it documents all the species of the other articles and adds some species to the list. The table summarizing the species of stingless bees in Tanzania can be found in Appendix A.

2.2 Colony structure

The bees of a nest can be classified in three classes, consisting of the queen, workers and drones (Kwapong et al., 2010).

The queen of a stingless bee nest is the mother of all the workers and starts out as a fertilised egg, laid by another queen. Her primary functions in the nest are laying eggs and directing all the workers through the release of pheromones. An example of that interaction is the release of a pheromone that inhibits the ability of workers to lay eggs (Kwapong et al., 2010; Nunes et al., 2014).

Figure 2.1: Brood of a stingless bee nest. Picture by Dr. H. P. Msanga (2019)

The workers of a stingless bee nest also start out as fertilised eggs. The larvae from those eggs are initially fed with the same jelly as the larvae that eventually become a queen, but quickly switch to eating worker jelly. Workers perform most of the tasks inside of the beehive like defending the nest, for example by encapsulating the intruder in wax. They also take care of feeding the larvae and foraging (Kwapong et al., 2010; Roubik, 2006).

Drones are the male part of the nest. They develop from unfertilised eggs and are fed with the same jelly as workers. The main task of drones in a bee nest is reproduction. For that purpose, they mate with virgin queens. That happens in mid-air with queens from other colonies on specific sites (Kraus et al., 2008; Kwapong et al., 2010).

2.3 Behaviour

In temperate regions, stinging honeybee colonies stop rearing brood and foraging during colder winter months. This is not the case in tropical regions, where temperatures stay high enough to enable both stinging and stingless bees to forage throughout the year. Stingless bees would not be able to sustain their colony throughout a colder period when foraging is not possible. Therefore, they are restricted to the tropics (Henske et al., 2015).

2.3.1 Foraging strategies

Earlier articles about the foraging behaviour of African stingless bees such as Ramalho et al. (1994) and Biesmeijer & Slaa (2004) explicitly mention a lack of articles about stingless bees at the time. That has since been solved as there have been quite a few studies that have discussed the foraging behaviour in stingless bees but most of them only cover the neotropical species. In recent times there have been some articles about African stingless bees although they remain rare and only by a few authors (Henske et al., 2015; Kajobe, 2007; Krausa et al., 2017; Tropek et al., 2018). However, these articles are all unsuitable in one way or another (e.g. Study area which is far away from Tanzania, too specific on one species of stingless bees) Therefore, the primary source for this chapter is the book Pot-Honey by Vit et al. (2013). This book is commonly used in other scientific articles as a general source of information about stingless bees and it contains a chapter dedicated to foraging behaviour by Hrncir & Maia-Silva (2013). As the knowledge about stingless bee foraging is limited, this study will serve as a reconnaissance study in that field.

Figure 2.2: Stingless bees returning to the hive carrying pollen in the pollen sacs on their legs

The stingless bees are a diverse group in terms of foraging strategies. Some species have expressed real specialization in their food sources. For example, *Trigona spp.* are necrophages who feed on the protein of carcasses and faeces while *Cleptotrigona spp.* steal from other stingless bee nests (Eardley, 2004; Roubik, 1989). Nonetheless, most stingless bee species forage for nectar and pollen (Henske et al., 2015).

Because of their eusocial nature, stingless bees collect food for their entire nest. Consequently, the success of a nest depends on the quality of their foragers. The forage mostly consists of nectar and pollen. Nectar is used as food for the foragers while pollen is used to feed larvae. That makes pollen especially important for the development of the bee nest (Potts et al., 2003). Both pollen and nectar are stored inside of the nest, to ensure food safety during a period of shortage (Hrncir & Maia-Silva, 2013). As a colony, stingless bees are generalists. However, on an individual level a stingless bee mostly visits one specific type of flower during a foraging trip. That indicates a high preference for that flower and is called ‘flower constancy’ (Meléndez

Ramírez et al., 2018). That flower constancy is mainly caused by three factors: preference, necessity and innate factors (Ramalho et al., 1994). It leads to a better mating of the flowers within a specific flower species due to less pollen being wasted on other flowers (Campbell & Motten, 1985).

Colonies of stingless bees are generally smaller than colonies of stinging bees with a few exceptions. These smaller stingless bee colonies mostly feed on plants which are not frequently visited by other species while the larger colonies tend to focus on gaining a competitive advantage through different foraging strategies (Ramalho et al., 1990).

To better explain that competition and consequently the foraging behaviour of those stingless bees, a differentiation must be made between a fundamental food niche and a realised food niche. The fundamental food niche is the niche a species occupies without competitors. However, in the presence of competitors a species must specialise more towards a specific food source. That is that species' realised niche (Biesmeijer & Slaa, 2006).

Fundamental food niche: forage sources available for stingless bees

The fundamental food niche of a stingless bee is mostly dependant on their tongue length. Bees with a long tongue can access nectar hidden deep within flowers. That nectar is often sugar rich, but it takes more effort and consequently more time for the bees to access. Therefore, bees select the flowers where the extra effort of reaching the nectar is rewarded with an extra supply of sugar. The optimal flowers for a stingless bee to visit are those where the depth of the nectar is equal to the tongue length of the bee (Harder, 1985; Hrncir & Maia-Silva, 2013).

In addition to tongue length, the fundamental food niche of stingless bees is also greatly influenced by the size and colour of the bees. Bees are insects which run the risk of overheating during a foraging session, especially in a tropical climate. Smaller bees exchange heat more quickly through convection. Consequently, larger bees are more prone to overheating when foraging in sunny spots than the smaller species (Pereboom & Biesmeijer, 2003). Therefore, larger bees start foraging a lot earlier in the day. The colour of the bee also plays a role in the foraging behaviour. Darker bees generally forage more in shade spots, again to avoid overheating (de Bruijn & Sommeijer, 1997; Hrncir & Maia-Silva, 2013).

This creates a temporal and a spatial separation in size and colour between stingless bees. Darker and larger bees can start foraging earlier, sometimes even before the sun rises. But they also overheat more easily and have to resort to shady spots when it gets warmer (Hrncir & Maia-Silva, 2013).

Realised food niche: forage sources reached by competition

The realised food niche of a bee is determined by the interaction of that bee with the environment. The strongest competition in terms of forage for stingless bees is with other stingless bees that are similar in size, colour, and tolerance to temperature. In other words, the main competition of stingless bees are other stingless bees with the same fundamental food niche (Biesmeijer & Slaa, 2006; Kajobe, 2007).

When talking about the realised food niche of a stingless bee, several strategies are used by stingless bees while foraging. The first strategy is called mass-recruiting and can be used by both aggressive and non-aggressive foragers. In that strategy, stingless bees mostly try to dominate a food source due to the sheer number of bees present. That behaviour is best observed when there is a large amount of food available. That is the case in plants that flower abundantly over a brief period. Those so-called 'mass-flowering' plants are the main source of food for the bees. The share of the annual food that comes from those mass-flowering plants can reach as high as 90%. When a plant of that type is small enough, a swarm of bees can even monopolise that resource against other foraging groups. Mass-recruiting bees are the only type of stingless bees to indicate the location of a food source. That indication is done by a pheromone trail and thoracic vibrations as opposed to the waggle dance done by honeybees (Hrncir & Maia-Silva, 2013). However, that strategy also has a major downside, i.e. the lack of exploration groups. Consequently, bees using that strategy do not discover new food sources as quickly as others (Hubbell & Johnson, 1978).

A second strategy is to scramble for forage. This strategy can be either individual or in group. Those bees discover new food sources more often but lack the numbers to dominate them in the way mass-recruiters do. Therefore, scramblers must go to relatively poor sites or reach the food source before the mass-recruiter. Another option is to join them when there is plenty of food available for both groups. In contrast to mass-recruiters, scramblers do not have the ability to communicate where a food source is located. Consequently, when a new food source is discovered the foragers in the hive move quickly but do not know where the source is located. The bees will all spread out and try to find the scent that was brought by scouts (Hrncir & Maia-Silva, 2013).

The last strategy used by the stingless bees is the strategy of insinuators. Solitary bees mostly use that strategy. When threatened by a dominant species, those species of bees will fly away from the source and return quickly to feed on the same source or a patch close by. When confronted with the same dominant species for more than once, the solitary bees will remain indifferent to them when foraging (Biesmeijer & Slaa, 2006; Hrncir & Maia-Silva, 2013).

2.3.2 Swarming

Swarming is an important natural process of colony multiplication. That ability to split a hive in that manner is only observed in honeybees and stingless bees. They are the only species where the queen of a colony cannot establish a new colony on its own (Engels & Imperatriz-Fonseca, 1990). However, there is a key difference between swarming in stinging bees and swarming in stingless bees, first described for neotropical species by Nogueira-Neto (1954) and later confirmed by others (Chuttong et al., 2014; Inoue et al., 1984). When swarming, a newly formed stinging bee colony will abruptly break the bond between the swarm and the colony. The swarm will take the old queen with them and move out when workers scout a new site. In contrast, stingless bee swarms will gradually break the bond with the colony and bring a young queen with them. A suitable site for a daughter colony will be scouted by workers and a transfer of resources will first take place. After that, the so-called 'virgin queen' will move but the bond between the mother and daughter colony will exist for up to half a year (Inoue et al., 1984). A downside of swarming in stingless bees is that the bees leave a small colony behind which affects production (Tutuba & Vanhaverbeke, 2018). Swarming only occurs when food is plenty, which makes swarming behaviour an indicator for the profitability of forage around the hive.

During the swarming process, stingless bee colonies can be caught by trap-nests in the wild. This is considered the most sustainable way to obtain new colonies of stingless bees as the bees can remain in their native habitat and the cost is only a new box. The concept of swarming is also used by stingless beekeepers to multiply their own nests (Jaffé et al., 2015). This concept of commercially multiplying colonies will be further explained in part 5.4.

3 Meliponiculture as a method for sustainable livelihood

Meliponiculture is the activity of keeping stingless bees as an additional source of income through the sale of their products like honey, propolis and others. The global demand for honey and hive products from both stinging and stingless bees exceeds the production. That great demand is also observed in Tanzania where the production cannot match local and global demand (Wagner et al., 2019). Beekeeping has a long history in Tanzania, first being described from 1949 to 1957 by Smith (1958). Beekeeping in tropical regions such as Tanzania is divisible in two main categories: honeybee keeping (apiculture) and stingless beekeeping (meliponiculture). This study focusses on the latter. However, the practice of stingless beekeeping has recently declined in favour of apiculture due to the higher volumetric production. Stingless bees have a lower honey production than stinging honeybees due to their smaller flight range (Eardley & Kwapong, 2013). That lower production also makes their honey more valuable. The demand for stingless bee products is high in Eastern Africa, even exceeding the production (Wagner et al., 2019). Furthermore, stingless bees are important for their contribution to ecosystem services. They pollinate various plants that are used as fodder for wildlife and domesticated animals. In addition, these plants also serve an important function as erosion control (Chidi & Odo, 2017).

Figure 3.1: Stingless beehives of a large stingless beekeeper in Mbokomu ward, Kilimanjaro. This beekeeper has both traditional log hives and box hives

3.1 Ecosystem services provided by stingless bees

Production of food and obtaining food security is considered to be the main reason to keep bees in Africa, even though the indirect benefits like pollination generate more income (Carroll & Kinsella, 2013; Kasina et al., 2009; Sagwa, 2021).

3.1.1 Pollination

The ecosystem services provided by bees as pollinators are obvious. It was estimated in 2015 that on a global scale that activity is worth between 235 and 577 billion USD (Potts et al., 2016). It was even estimated the value of the pollination services was 100 times the value of the honey produced by the bees. This makes pollination by bees a more important ecosystem service than the honey produced by them (Bradbear, 2009). In addition, bees also provide a stabilising effect on the pollination of crops (Klein et al., 2007).

Stingless bees can be used as pollinators for a variety of crops and other plants. They improve the yields of most plants, even those who rely on wind for pollination (Sihag, 1995). Honeybees are most often used for that application. But the use of stingless bees has two key advantages. Firstly, stingless bees can be housed close to their owner's home due to their inability to sting. That is especially an advantage in the homegarden system as in North-Eastern Tanzania where the defensive stinging behaviour of the local bee species has been a reason for many famers to abandon beekeeping entirely. The second key advantage of stingless bees is the ecological advantages they bring to pollination. The bees are indigenous to the region and contribute to the conservation of biodiversity by pollinating indigenous plants (Meléndez Ramírez et al., 2018).

3.1.2 Honey

Honey is a product produced only by honeybees and stingless bees and sold all over the world (Nordin et al., 2018). Given that the honey production of stingless bees is lower than that of honeybees, while the average price of stingless bee honey is higher (Biluca et al., 2014). Lower production, in combination with less global recognition also makes stingless bee honey a product that is less documented compared to the honey of their stinging counterparts.

In most articles both types of honey are compared to each other with the honey of stinging bees as a reference. The main differences are a higher moisture content, a higher acidity, higher antioxidant and biological activities and a lower level of carbohydrates in the honey of stingless bees. Those characteristics make the honey of stingless bees a sweet, but also slightly sour product with a fluid texture (Ávila et al., 2018).

Over the last twenty years, the interest in stingless bee honey as a component in pharmaceutical and cosmetic products has grown substantially (Jalil et al., 2017). However, due to the relatively low production and higher price, it is not well regulated and poorly marketed on a global scale (Ávila et al., 2018). On a local scale, honey from stingless bees is used for many different purposes like the brewing of beer, raw consumption but also in medicine. Medicinal use is the most common application of stingless bee honey in indigenous communities throughout Sub-Saharan Africa (van Huis, 2020). It will be further elaborated in chapter 5.1.1.2.

To improve the marketability of stingless bee honey and allow sale on a larger scale, farmers must be able to ensure their honey meets the necessary quality standards which are specified in TZS1966:2020 for Tanzania specifically. This standard has been established by TBS (Tanzanian Bureau of Standards), but it has not been used yet to certify any organisation that distributes stingless bee honey. The certification of stingless bee honey falls outside the scope of this study, but it would provide a useful next step for research on stingless bees with exciting potential benefits for local beekeepers.

3.1.3 Propolis

In addition to honey, stingless bees also produce some other products that could be marketed by beekeepers. The most significant of those products is propolis or bee glue, a product made by the bees from a resin collected from exudates of plants and mixed with bees' wax. Bees use propolis as a material for various repairs in the hive like filling in gaps and strengthening the walls of their nest (Almutairi et al., 2014; Bankova et al., 1999).

The interesting properties of propolis like antibacterial, antiviral, and antifungal activity among others make that a substance that has gotten the attention of scientists since the late 1960s. Those properties and the composition have been studied for Brazilian stingless bees by Bankova et al., (1999) and Campos et al. (2015). However, those studies have also found that the composition of propolis varies greatly between different geographical locations due to the difference in plants used as a source by the bees. The composition of propolis from Africa is not well known, which makes it hard to make any predictions. Consequently, this can form another part in the further research for standardizing stingless bee hive products which was mentioned in the introduction (Almutairi et al., 2014; Bertelli et al., 2012). Like honey, the amount of propolis produced by stingless bees is lower than by *Apis* species. But if the stingless bee industry can gain traction in Africa as it has done in Brazil over the last years, there is real potential of selling propolis from stingless bees (Salatino et al., 2019).

3.2 Social structure around stingless beekeeping

Like most subjects on meliponiculture in a rural context, information about the social aspect of stingless beekeeping is scarce with most studies focussing on neotropical areas.

One of those studies from the neotropics contains data about 251 beekeepers from Brazil, compiled by Jaffé et al. (2015). It investigated the influence of a social network of beekeepers and the influence of how many years of experience the beekeeper had. An interesting discovery was that the years of experience were more of a key factor than the social network of beekeepers in how much honey was sold by the beekeepers. That indicated that the limiting factor of stingless beekeepers was mostly technical knowledge. Farmers who have practiced beekeeping for many years have more experience which enables them to produce honey more sustainably. Consequently, they can sell more honey due to a constant high demand. Another factor that increased sales in Brazil is if the beekeepers also cultivated crops. That suggests that the sale of honey is often on markets where products from agriculture are also traded (Jaffé et al., 2015). The study suggested a course about the management of stingless bees to help improve the knowledge about the exploitation of meliponiculture and thus the production, but that is outside the scope of that study.

3.2.1 One-parent families have the largest possible gain

One-parent families are traditionally the most vulnerable to the new challenges that climate change poses. A reaction from agricultural households in Tanzania is to diversify their income streams (Paavola, 2008). Stingless beekeeping is an opportunity for villagers because they have often stopped practicing traditional apiculture due to the defensive behaviour of the bees, even when their parents did practice apiculture. The most common honeybee in Eastern Africa is *Apis mellifera scutellata* and it is highly defensive (Chidi & Odo, 2017; Wagner et al., 2019).

A study performed in Ethiopia by Kidane et al. (2021) also found that wild honey hunting by females is a very rare occurrence (2 of 60 interviewed). That low share of bee hunters being female is attributed to the fact nest hunting is mostly considered to be a male job. However, the fact that moving through a forest alone is generally considered taboo for women could also play a part in that statistic. That makes meliponiculture close to a settlement an even more attractive opportunity and provides an opportunity for one-parent families to have a sustainable income from the products provided by the bees.

3.2.2 Stingless bees in local culture

In traditional knowledge of Chagga people, it is often believed that when a swarm of stinging bees comes to a house it brings a bad omen. It is an indication that something bad is going to happen to the family. However, it is indicated that it could also be a sign of luck or richness. That different explanation is probably due to the fact that the arrival of a single bee flying around a person or lands on someone is mostly perceived as a sign of getting good news (van Huis, 2020). These cultural aspects should also be taken into consideration when conducting research about the swarming behaviour of stingless bees. They are not the focus of this research, but they do provide an interesting opportunity for further investigation which will be elaborated in chapter 6.7.3.

3.3 Financial incentives for stingless beekeeping

Meliponiculture provides a new opportunity to financially improve livelihoods in the South. Especially of one-parent families as mentioned in the previous part. The financial aspect is an important part of that project. When crops are replaced with plant species responsible for a better resistance against land degradation, families lose part of their income. That lost income can be compensated by revenue from meliponiculture, as the bees use those newly planted species as a food source.

As previously explained in part 3.1.1 about pollination, the largest profit by far which is provided by stingless bees are their pollination services. However, that is not a direct income source and therefore not the main reason for people to become beekeepers. That main reason was to have an extra source of income from the sale of honey and possibly by-products (Sagwa, 2021).

The honey production by stingless bees is lower than honeybee production. But stingless bee honey is widely described as a product that can fetch higher prices in markets. Stingless bee products also have potential as luxury products (Jaffé et al., 2015).

3.4 Biological traits of stingless bees in a production environment

Stingless bees have some biological characteristics that make them an excellent choice for beekeeping in an agroforestry homegarden system. The most obvious advantage is the suitability of practicing meliponiculture close to a settlement, which would be the case in a *kihamba* system. That advantage is due to the lack of a functional stinger in the bees (Slaa et al., 2000). Another advantage of stingless beekeeping is that unlike *Bombus* species, stingless bees do not die after reproduction. That feature, in combination with the fact that colonies of stingless bees are naturally long-lasting ensures that individual stingless bee colonies can be kept up to 60 years (Murillo, 1984; Slaa et al., 2006).

3.4.1 Important plants

The important plants for stingless bees in meliponiculture have been described most extensively by Ramalho et al. (1990). That review was written in about the neotropics, making it less suitable for application in Northern Tanzania, but it does provide information on the fact that stingless bees visit a wide variety of plants, but the main source of energy only comes from a few among them.

The research for important bee plants has also been conducted on the African continent. Those articles conclude that stingless bees in Africa visit a wide variety of species for nectar and pollen collection with *Coffea arabica* and *Zea mays* being immediately recognisable as potential important plants for an agroforestry homegarden (Kajobe, 2007, 2013; Kimaro et al., 2013; Kinati et al., 2012; Slaa et al., 2006). Within these sources, the source by Kajobe (2013) is clearly the most extensive.

Another use for plants by stingless bees is nesting. They nest in hollow tree trunks, walls, fences or underground cavities depending on the species of stingless bees (Kajobe, 2013). This must be considered when characterising plants for bees. However, it is less important in an agroforestry homegarden system as almost all beekeepers use hives for housing the bees.

3.4.2 Nesting

The nesting behaviour of stingless bees in the wild is diverse and depends on the type of bee. Due to that diversity, the entrance of stingless bee nests is often used as an indicator for the species. Contrary to stinging bees, honey and pollen of stingless bees is not stored in honeycombs, but in pots. The pots on the extremities of the nest contain the ripened honey or even nectar during periods of heavy flowering. Pollen is stored in the pots around the brood cells. Those brood cells are recognisable due to their spherical or ovoid shape in contrast to the more egg-shaped or even conical pots (Roubik, 2006)

Figure 3.2: Opened stingless beehive with pollen storage on the left side, brood in the middle and honey storage on the right side. Picture by Dr. H. P. Msanga (2019)

In tropical areas, stingless bees form perennial colonies due to their foraging behaviour (Wilson et al., 2021). In addition, they do not experience strong pressure to change nesting sites regularly due to parasites (Roubik, 2006). That implies that stingless bees have a lower susceptibility to pests than tropical honeybees (Morse, 1994).

3.4.3 Multiplication of colonies

Successful multiplication of colonies is vital to any sustainable effort of meliponiculture. New colonies can be bought from other beekeepers or multiplied by the stingless beekeeper. As mentioned in part 2.3.2, when the stingless bees are swarming, there is an opportunity for stingless beekeepers to trap a new colony. That method is considered by Jaffé et al. (2015) to be the most sustainable approach to multiply colonies of stingless bees. That study also found that a course about meliponiculture elevates the chance that beekeepers will multiply their colonies successfully. That is explained by the fact that the multiplication of colonies is not an easy procedure. It requires specialised knowledge of when and how to perform certain procedures. One example of that is to know when to extract the brood discs that are in the right stage of their development and ready to be split from the colony (Jaffé et al., 2015).

3.4.4 Challenges and opportunities for stingless beekeeping in Tanzania

Constraints for beekeeping in Northern Tanzania specifically were not well known until the article by Kimaro et al. (2013) was published about stinging beekeeping. The knowledge in the article was later compiled with other studies about beekeeping in Africa into a larger study about beekeeping constraints in Tanzania by Tutuba & Vanhaverbeke (2018). But because of the geographical relevance of the study, the article by Kimaro et al. (2013) will first be considered separately. That article is the first large scale interview of villagers in Northern Tanzania about constraints for beekeeping specifically and could be expanded to possible constraints for stingless beekeeping which makes it relevant for that study. Those main threats could be summarised as below in Figure 3.3.

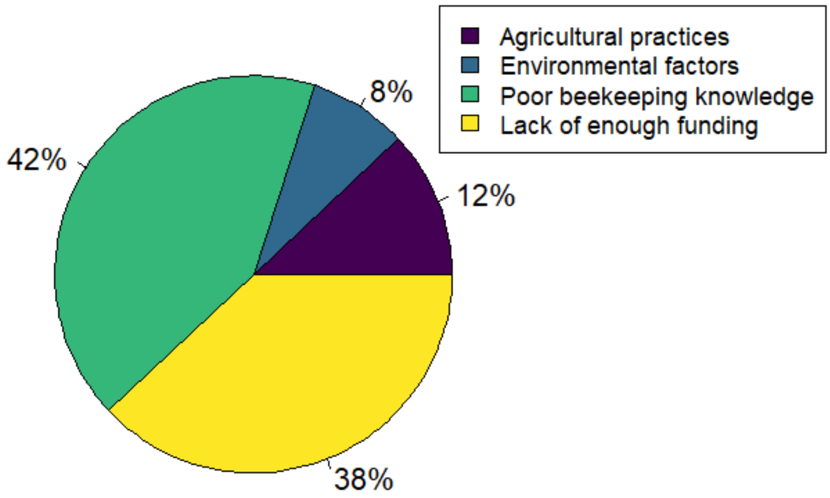

Figure 3.3: Major beekeeping challenges reported in Arumeru. Adapted from (Kimaro et al., 2013)

The study found that the main challenges that beekeepers face are the lack of beekeeping knowledge (42%) and a shortage of funds (38%). A proper beekeeping course has been mentioned in previous parts as a way of increasing the yields of colonies. Tanzania's policy about beekeeping and forest management is rather progressive. However, the village leaders have reported no beekeeping officers or invitation to training in the last five years. That leads to the conclusion that there are good services available for stinging beekeeping, but they are not implemented correctly by the district councils of the country. That could also be the case for stingless beekeeping. The other significant challenge in beekeeping was the low availability of funds. That has limited the ability of villagers to buy the modern beekeeping equipment required for the efficient production of honey. As a consequence, most (95%) of the villagers in the study reported to still use traditional log hives because of a lower cost (Kimaro et al., 2013).

The assessment of constraints for beekeeping in Tanzania was a more extensive but also more general article by Tutuba & Vanhaverbeke (2018). That article compiled data from Ethiopia, Tanzania, Botswana and even from one article conducted in Canada about the threats beekeepers face and provided an extension for the constraints which were already described by Kimaro et al. (2013). As seen below in Table 3-1, the constraints mentioned in the various articles were grouped into internal and external factors.

Table 3-1: Internal and external constraining factors for commercial stinging beekeeping. Adapted from (Tutuba & Vanhaverbeke, 2018)

No.	Internal factors	External factors
1	Death and size of bee colony	Adequate extension support and lack of institutional support
2	Honeybee pests and disease	Casual burning
3	Lack of beekeeping knowledge and skills	Drought
4	Lack of reliable financial profiles	High-risk perception of beekeeping
5	Leadership, management, and governance issues	Inadequate institutional systems and structures
6	Low hive occupancy rate and hive productivity	Lack of a business orientation to apiculture
7	Poor processing methods	Lack of financial support
8	Shortage of beekeeping materials	Limited involvement of women and youth
9	Weak financial capacity of co-operatives	Limited skills, capacity, and extension service support
10	Weak sanitary and quality assurance service	Marketing problems. Low market prices and poor marketing systems. Limited market information
11		Financial institution perception of beekeeping
12		Pests, predators, and honeybee diseases
13		Shortage of bee forage/reduced honeybee fodders
14		High cost of modern hives and equipment
15		Transversal or cross-cutting themes: environment, climate, and gender
16		Unavailability of modern beekeeping technology

The most crucial factors regarding production are the absconding and the rate of beehive occupancy. Abscondment is the key factor for that study. It was also mentioned as a threat to rural beekeeping in Africa in the study by Kimaro et al. (2013) among others (Jeil et al., 2020). That behaviour naturally occurs when bees abandon their nest. It was found that that behaviour occurs mostly due to dirty living conditions, pests and predators and poor harvesting practices. For example, villagers often use open fire to control the nest while it is being harvested for all valuable parts of the nest. That kills a large part of the colony and leaves them with no food due to the harvest. This is another situation that can be avoided by a proper course on how to manage and harvest a hive. A further investigation of what causes abscondment in stingless bee colonies and how to avoid it is a part of this study and will be further elaborated in chapter 5.3.

4 MATERIALS AND METHODS

4.1 Study area

The study area used was situated in the mountainous landscapes of Northern Tanzania. More specifically, smallholder farmers practicing stingless beekeeping on the slopes of Mt. Kilimanjaro and in the South Pare mountains were surveyed. The data point which falls outside of the catchment on Mt. Kilimanjaro represents the location used for pre-testing the survey in Kibosho ward. In the region of the Northern mountainous landscapes of Tanzania, a tradition of smallholder farmers practicing stingless beekeeping is present but poorly documented.

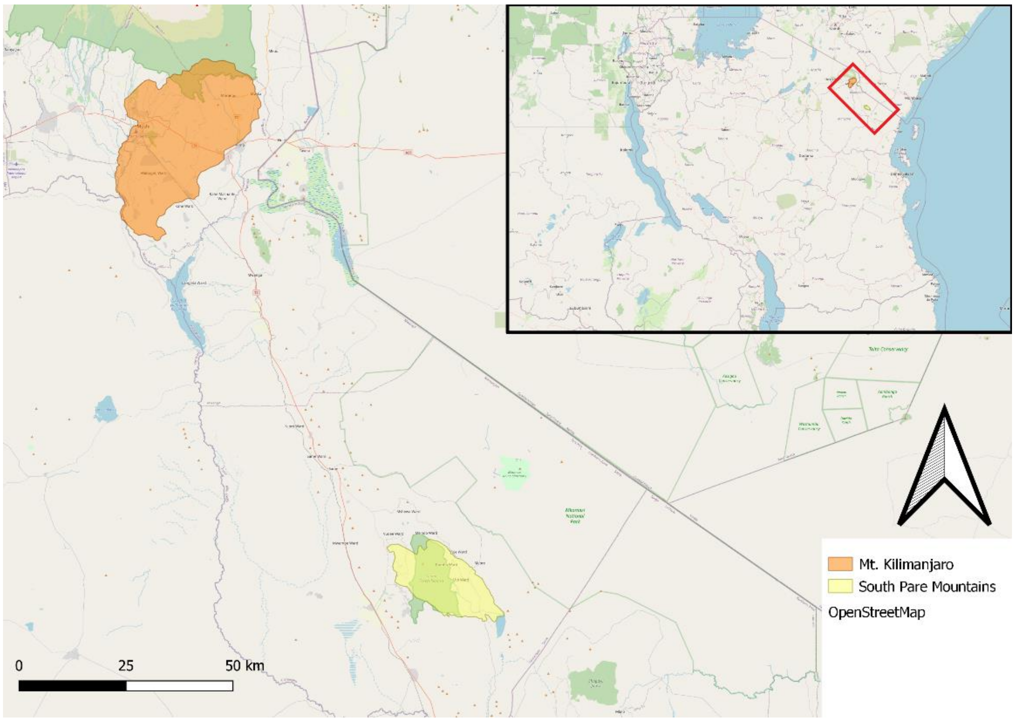

Figure 4.1: Location of the study area within Tanzania

Within these landscapes, a good spatial distribution was sought between the limits of 700 and 2000m above sea level. That range was chosen because it provides the typical examples of agroforestry homegardens where stingless beekeeping is practiced. The zone is mostly inhabited by smallholder farmers. The surveyed communities were Chagga for Mt. Kilimanjaro and Pare for the South Pare mountains as these are the main inhabitants of these regions. 28 smallholder farmers practicing stingless beekeeping were surveyed on Mt. Kilimanjaro and seven were surveyed in the South Pare mountains.

4.1.1 Mt. Kilimanjaro

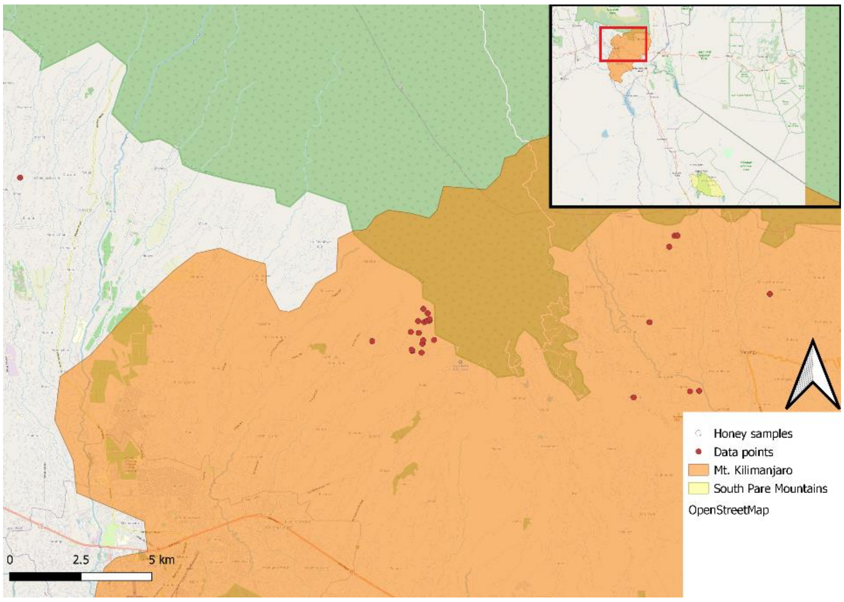

Figure 4.2: Distribution of respondents (n=28) on Mt. Kilimanjaro

Moshi district is the main district where surveys were conducted for this study. It lies between longitude 37° to 38° East and latitude 2°-30'-50° South of the equator. The district is bordered by Rombo district to the North, Mwanga and Simanjiro district to the South, Hai district to the West and Kenya to the East. The district is subdivided into 4 divisions, 32 wards and 157 villages (Moshi District Council, 2016).

Rainfall in the district is highly dependent on the altitude. The lowlands (700-900m a.s.l.) can receive between 400mm and 800mm of rainfall annually. The midlands (901-1500m a.s.l) receive between 900 and 1400mm of annual rainfall and the highlands (1501-5895m a.s.l.) receive 1401-2000mm of annual rainfall. This rainfall is split between two rainy seasons: the normal rainy season is between from March to June and an additional one is between October and December. The temperature in Moshi district averages 26°C during the day. The lowest temperatures occur between June and January and average 15°C. The highest temperatures in the district average 31°C and the occur between February and November (Moshi District Council, 2016).

The lowlands have the lowest population density of the district as it reaches 15-30 people per km². In contrast, the highlands have a population density that ranges between 400 and 800 people per km², which makes it the most densely populated area in the district (Moshi District Council, 2016)

4.1.2 South Pare mountains

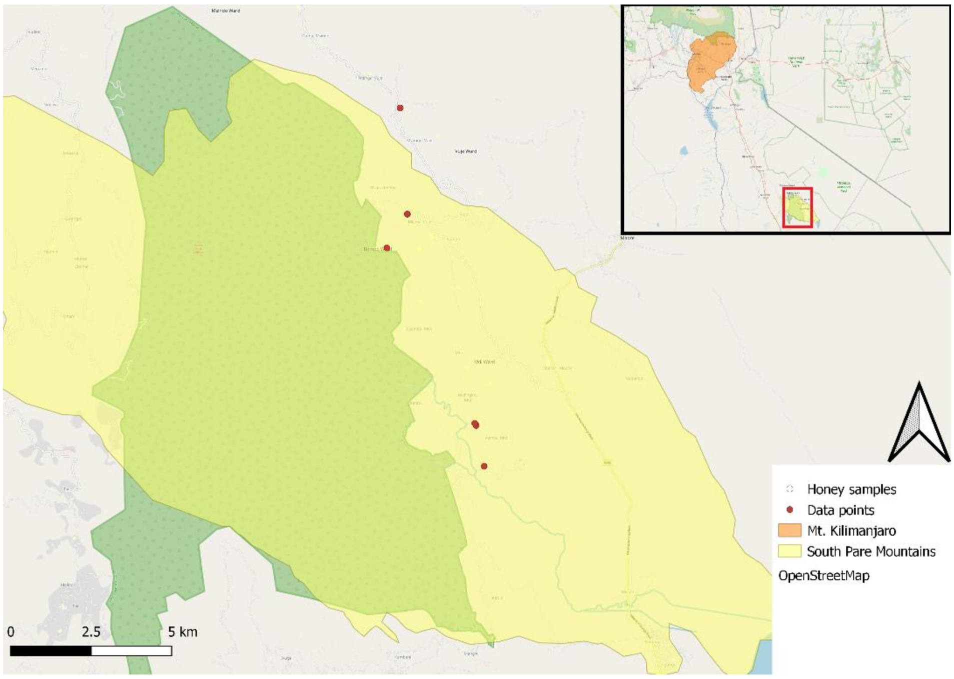

Figure 4.3: Distribution of respondents (n=7) in the South Pare mountains

The landscape of the South Pare mountains is located within the Eastern Arc mountains, which range from South-East Kenya to Eastern Tanzania. The regional average temperature ranges between 15°C and 20°C, with a bimodal rainfall pattern. This rainfall pattern consists of long rains between March and May and short rains between October and December (Finch et al., 2017; Nicholson, 2000). The highest ridge of the South Pare mountains is marked by Chome Forest Reserve, which covers an area of 14,283ha (Finch et al., 2017).

4.2 Methods of information collection

4.2.1 Surveys

The surveys conducted to gather the information were based on earlier surveys by Jaffé et al. (2015) and Karikari & Kofi (2007). The initial questionnaire contained questions on the experience of the beekeeper, the plants used by bees, management techniques, the yield of the hive and the number and type of hives, among others. The survey did not question any personal information. Some of the questions about beekeeping practices were open ended or asked for opinions. This allowed the respondents to include more useful information and contextual feedback. In addition, it allowed for a better understanding of the beekeepers' thoughts and attitude about the context of the survey.

The survey was pre-tested in Kibosho ward (Moshi Rural District) with a successful stingless beekeeper. Even though the ward of Kibosho is located outside of the boundary set for the landscape of Mt. Kilimanjaro, it still provides valuable data and a good starting point. A slight modification of the questionnaire followed for more accurate responses. Using this survey, 34 other smallholder farmers practicing stingless beekeeping were surveyed. To maximise the number of data points, stingless beekeepers with only empty hives were also considered for sharing their experience although this was a rare occurrence (2 of 35).

Figure 4.4: Pre-testing of survey in Kibosho ward (Moshi Rural District)

Key informants for stingless beekeeping were identified based on the opinion of other beekeepers. A more extensive survey was used for these beekeepers. Surveys with other beekeepers were limited to mostly basic questions. To identify the beekeepers, a snowball sampling technique was used where every interviewed beekeeper was asked if he knew any other beekeepers. The surveys were conducted in a semi-directive style, making it less of an answer session and more of a conversation about stingless beekeeping (Huntington, 2000). A full version of the corrected survey can be found in Appendix D. The data was collected between July and September 2021.

4.3 Data processing and statistics

Most data was first entered in Excel® (Version 2203, Build 15028.20160). This data was then used to generate descriptive statistics in R (R Core Team, 2020). When necessary, normality was tested using Shapiro-Wilk test and equality of variances was tested using Levene's test. All statistics were tested on a 95% confidence interval. As this was a reconnaissance study, the focus was on describing the current state of stingless beekeeping in Northern Tanzania. Therefore, in-depth statistics were not a part of this study. The descriptive statistics provide a clear image of what is present today and where opportunities for further research are present.

4.3.1 Characterisation of the homegardens

Homegardens in the different landscapes were characterised based on their composition. The different layers which are typical for the agroforestry systems were all assessed separately. Each species was judged on its relative abundance in the respective layer. The information was recorded and will be compared to the data generated by the pollen analysis (Chapter 5.7).

4.4 Collection of honey samples

Nine honey samples in total were obtained from different beekeepers in Northern mountainous landscapes of Tanzania. One was obtained in Kibosho, four in Mbokomu, three in Kilema (selected wards in Moshi Rural District), two samples were collected in Mtii and Bombo wards in Same District, South Pare mountains.

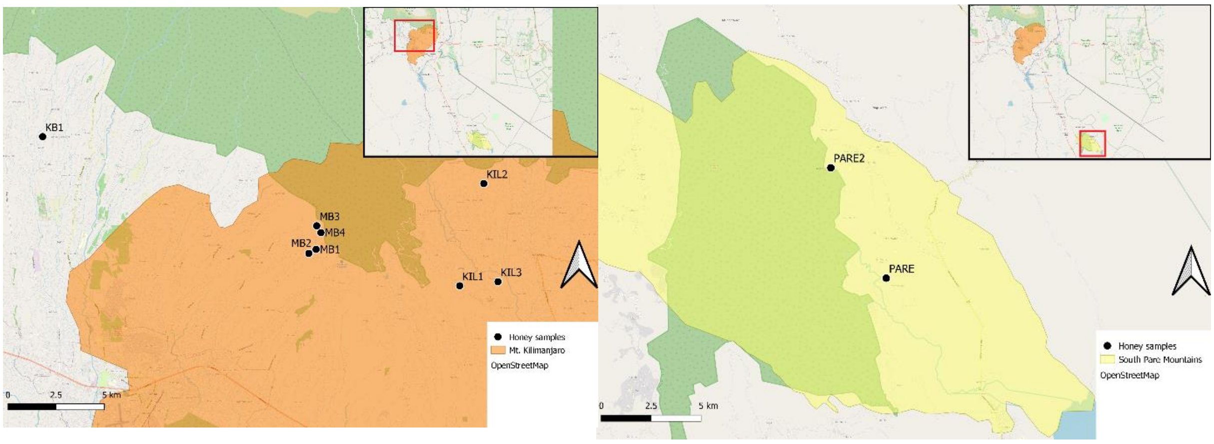

Figure 4.5: Honey sample collection sites on Mt. Kilimanjaro (left) and in the South Pare mountains (right)

When the beekeeper had some honey in stock, a small sample of 50 mL or more was obtained from this stock and stored in a clean plastic bag. These samples were all be subjected to pollen analysis (also referred to as melissopalynological analysis) for evaluating which pollen are most common in the honey. That will in term lead to an identification of the plants most frequently visited by the stingless bees.

4.5 Pollen analysis

For the microscopical identification of the pollen, a method without acetolysis was chosen as this is not necessary due to the good preservation of pollen in honey (Louveaux et al., 1978). The method used for the preparation of the slides was based on the method explained by Von Der Ohe et al. (2004). However, the glycerin jelly was applied to the slide directly in contrast to application to the cover slip as explained in the article.

For each sample, 200 pollen were counted. Pollen analysis is a field of study which requires a lot of experience for an identification on the level of individual plant species. Therefore, it was chosen to identify the pollen up to the family level. Next, they were classified for their relative abundance in the sample according to the classes of frequency determined by Louveaux et al. (1978). These classes are:

- “Predominant pollen” for pollen which make up more than 45% of the pollen grains counted
- “Secondary pollen” for pollen which make up between 16 and 45% of pollen counted
- “Important minor pollen” for pollen which make up between 3 and 15% of pollen counted
- “Minor pollen” for pollen which make up less than 3% of pollen counted

The main reference material used for identification of the pollen is the atlas by Schüler & Hemp (2016), in combination with other sources (Astolfi et al., 2020; *Base de Donnée Palynologique de Référence de l'ISEM*, n.d.; *Global Pollen Project*, n.d.; *PalDat*, n.d.; Chakraborty et al., 2016; Gosling et al., 2013; Silva et al., 2020; Soares et al., 2017).

4.6 Development of a decision support application

The application was based on an earlier idea and desktop application by Van Gysel (2017). A new smartphone version was developed in Xamarin and shows the number of flowering nectar and pollen sources for stingless bees in each month of the year. The data genererated by Kajobe (2013) was used for the establishment of a database. The application can be used to compare the availability of forage for the bees throughout the year. In addition, it can be used to explore the forage availability for stingless bees in areas where stingless beekeeping is currently not a common practice.

4.7 Floral calendar

A floral calendar is a basic necessity for stingless beekeeping. It lists the plants which are important as bee forage and their flowering times. It allows the beekeeper to identify the most important forage sources for the bees and adjust the time of harvesting accordingly. For the floral calendar, data from the pollen analysis will be combined with the plants mentioned by beekeepers during the survey. The data on flowering times of plants was obtained from various online sources.

4.8 Approach

The following graph is a summary of how all the collected data and samples will be translated into functional results. It serves as a roadmap for the following chapters about the results.

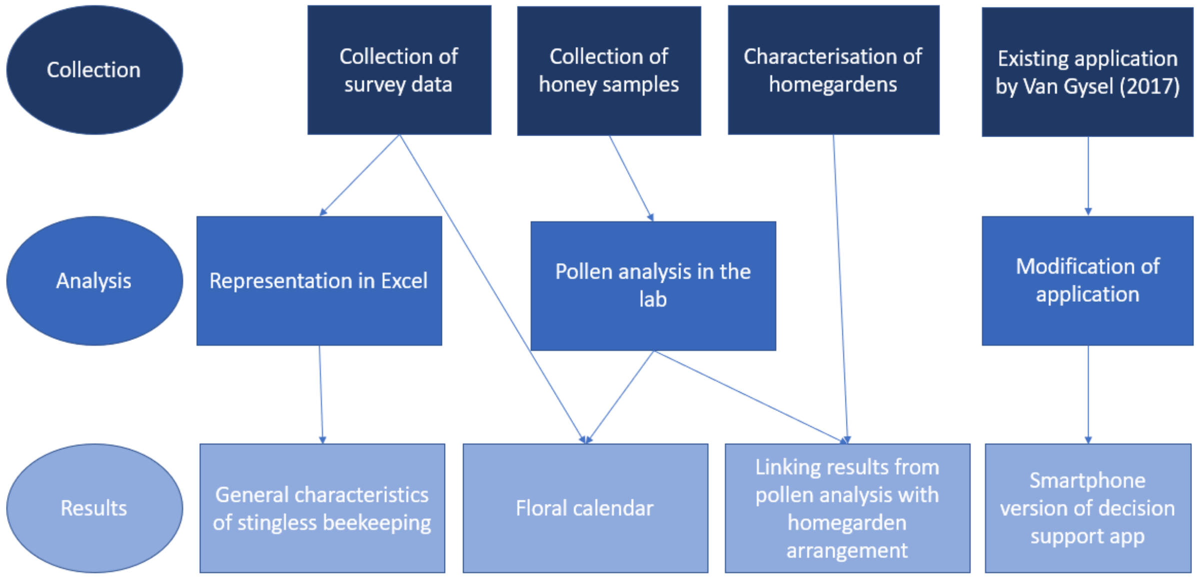

Figure 4.6: Approach for obtaining the projected results with the data and samples, collected during the field campaign

The first part of the results about the typical characteristics of stingless beekeeping will serve as guidance for further studies. The floral calendar can serve as a first document for stingless beekeepers as it is a basic necessity for any beekeeping effort. In addition, the results from the pollen analysis linked with homegarden arrangement can provide valuable information to stingless beekeepers on what is already valuable for their stingless bees and how they can improve their homegarden in the future. This can be supported by the results from the decision support app as it provides an applied, physical version of this work.

5 RESULTS

Due to the lack of previous research on African stingless bees, the collection of results had to start with basic questions. The answers to these basic questions were obtained through a survey with smallholder farmers practicing stingless beekeeping.

As the focus of this work was always on providing direct practical tips for the smallholder farmers, the data is mostly represented without any calculation. Each aspect can be subject to further research on its own to provide a more in-depth look into the factors influencing the answers provided. Right now, this work already allows to form an image on stingless beekeeping in Northern Tanzania through simple representations on the data.

5.1 Ecosystem services provided by stingless bees

Smallholder farmers benefit greatly from the ecosystem services provided by stingless bees. Consequently, they can be used to encourage the smallholder farmers to start with stingless beekeeping. The ecosystem services provided by stingless bees are categorised as non-wood forest products and consist of honey production and pollination.

5.1.1 Honey as the most popular benefit of stingless beekeeping

For most beekeepers, the sale of honey was the main reason for obtaining a stingless bee colony. This means there is still an opportunity for promoting the sale of other hive products like propolis and wax in the future. However, the focus of this part will mostly be the optimalisation of honey production as there is already market demand for this product.

5.1.1.1 Harvesting twice effectively doubles production

One of the main topics of the surveys was honey production by the stingless bees. This was surveyed to 27 smallholder farmers practicing stingless beekeeping. As mentioned previously in part 3.1.2, stingless bees produce less honey than the stinging honeybees which makes their honey more valuable. The yearly production of honey did not vary greatly between the beekeepers who were surveyed. Most reported between 2 and 3 litres of honey per hive annually. However, when beekeepers harvested twice per year, this effectively doubled their total harvest to around 5 litres of honey, as shown in Figure 5.1. This was tested using Welch's T-test, as both samples were normal (Shapiro-Wilk test: $p=0.1295$ and $p=0.4868$), but the variances were not equal (Levene's test: $p=0.0447$). A one-sided Welch's T-test with showed that beekeepers who harvest twice a year gain significantly ($p=0.02495$) more honey than beekeepers who harvest only once. The factors which influence the ability to harvest twice are discussed further in chapter 5.5.

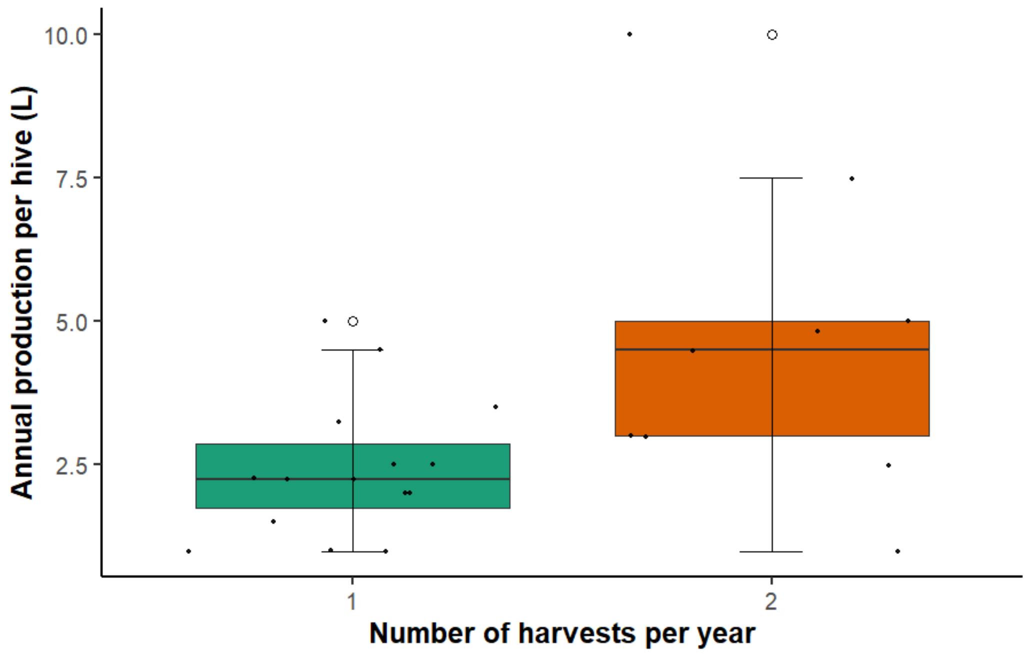

Figure 5.1: Annual production per hive in relation to number of harvests per year

5.1.1.2 A commercial context increases the value even more

The honey produced by stingless bees is a valuable product. The majority (88.2%, n=20) of use cases was as a medicine against conditions like asthma and coughing. A litre of stingless bee honey could be sold between 30K (1K=10,000) and 35K Tanzanian Shillings (abbreviated as TSh) locally or up to 45K TSh in larger towns (1 EUR = 2522 TSh as of 24th of April 2022). Almost all beekeepers mentioned that the demand for stingless bee honey was higher than the supply which meant they often kept some stock for family members or close friends. Honey can be kept for up to 10 years in a closed container due to its antibacterial and antiviral properties, so storage was no problem. Most beekeepers kept their honey in empty plastic water bottles and did not take any additional measures to safeguard the quality.

5.1.1.3 A system for quality assurance as a necessary condition

When interviewing beekeepers about the quality of honey, one ward specifically stood out from the rest. This was Mbokomu ward where beekeepers specifically thought their honey was superior in quality to others. Most (4 of 7) of them attributed this difference in quality to a larger variety in flowers used by the bees in the area. One beekeeper thought that honey from other regions was mixed by intermediaries which lowered their quality.

The local methods for checking the quality of honey were also shared. These included:

- Even dark colour throughout the honey, when this was not the case it indicated a dilution of stingless bee honey with honey from stinging honeybees
- Stingless bee honey should have a good viscosity. When pouring the honey, it should flow in a continuous stream. When the honey drips, this is a sign that it has been diluted with water.
- When putting a drop of honey on paper, it should not leave moisture on the other side of the paper, this would indicate an addition of water.

5.1.2 Pollination often exceeds honey production in terms of generated revenue

The main ecosystem service in terms of revenue for farmers is not always honey. Stingless bees also provide pollination which often exceeds honey production in terms of generated revenue (Bradbear, 2009). However, when surveying the smallholder farmers about their reasons for starting stingless beekeeping, pollination never came up as the main reason. When surveying smallholder farmers on Mt. Kilimanjaro whether they noticed a difference in yield from their plants after starting stingless beekeeping, 62% (n=13) of them reported to noticing a difference. Coffee was often mentioned specifically as a crop where a significant difference could be observed.

Within the beekeepers who were interviewed in the South Pare mountains, none (n=6) saw a difference in yield of their crops due to the bees. A possible reason for this will be further elaborated in part 6.1.1.

5.2 Social structure around stingless beekeeping

One of the main advantages of stingless beekeeping in homegardens is that women and children can help with beekeeping activities due to the lack of defensive stinging behaviour of the bees. However, in most situations men were still the main beekeeper in the family. The percentage of female beekeepers was not regionally related as the proportions in the South Pare mountains (n=7, 14.3% female) and on Mt. Kilimanjaro (n=28, 28.6% female) were similar. When women were the main beekeeper of the family, this was mostly since they were the only parent of the family. Children were never the main beekeeper of the family.

5.2.1 Experience in stingless beekeeping as a geographical differentiator

When comparing the two landscapes in terms of the experience of the beekeepers, this exposes a major difference which can explain why the landscapes differ so greatly in other ways. On average, beekeepers on Mt. Kilimanjaro (n=28) have 10.6 years of experience in stingless beekeeping. This was almost double of the experience that was observed in the South Pare mountains (5.5 years, n=6). In places where beekeepers had more experience, this can be attributed mostly to a few beekeepers with a lot of experience who promote the activity locally.

The experience of a beekeeper can be correlated with the source of their first colony, this is represented in Table 5-1.

Table 5-1: Source of first colony correlated with the average number of years of experience for stingless beekeepers on Mt. Kilimanjaro (n=27)

Source of first colony	Number of beekeepers	Average number of years of experience
Bought	7	5.6
Gift	4	6
Inherited	4	19.5
Separation	1	5
Wild catching	11	13.9

The beekeepers who were beekeeping for the longest time (19.5 years on average) were those who had inherited their colonies (4 beekeepers). Those who had a little less experience (13.9 years on average) mostly got their colonies from wild catching. The location where they obtained the colony varied according to the beekeeper. Some got it from the forest and others caught the bees in a tree in their own homegarden. The tree species from where smallholder farmers were able to obtain stingless bee colonies will be further discussed in chapter 5.6.3.

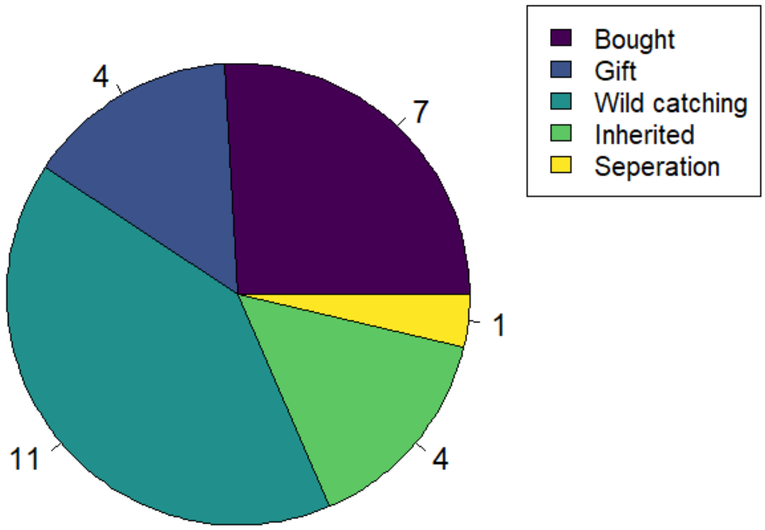

Figure 5.2: Number of beekeepers who obtained their first colony through each source on Mt. Kilimanjaro (n=27)

As represented in Figure 5.2: Number of beekeepers who obtained their first colony through each source on Mt. Kilimanjaro (n=27) wild catching was the primary source for the first stingless bee colony of beekeepers on Mt. Kilimanjaro (11 beekeepers). This further strengthens the supposition that stingless beekeeping has quite some history in the Kilimanjaro region as the average experience of this group almost reaches 14 years. Those who started stingless beekeeping more recently, shifted to buying their first colony from other beekeepers. That was the case with most beekeepers who had only recently started (on average 5.7 years of experience). This trend can be explained by the closing of the forest for things like catching wild colonies. The closure of the natural forest makes it harder for smallholder farmers to catch bees in the wild. In addition, as more smallholder farmers obtain a colony, it becomes easier to know someone who sells colonies.

The tradition of stingless beekeeping is much younger in South Pare mountains, with the average experience being 5.5 years. Most beekeepers who started did this through getting a recommendation by neighbours. Stingless beekeeping was relatively rare in the South Pare mountains and beekeepers who did not practice it showed no intention of starting. The beekeepers from the neighbourhood thought this was due to a large perceived risk for the initial investment. Even though the initial investment is high at around 100K Tsh for a new full hive, it is also an investment which is quickly re-earned as the honey harvest of one year can yield around five litres of honey. This honey can be sold for around 30K Tsh per litre, which means one hive can muster around 150K Tsh per year depending on the harvest.

Table 5-2: Source of first colony correlated to average number of years of experience in South Pare mountains (n=6)

Source of first colony	Number of beekeepers	Average number of years of experience
Bought	3	5
Wild catching	3	4.5

The observed trends on Mt. Kilimanjaro were less apparent in the South Pare mountains. A simple explanation for this would be the smaller sample size and the lack of smallholder farmers practicing stingless beekeeping for longer than 15 years.

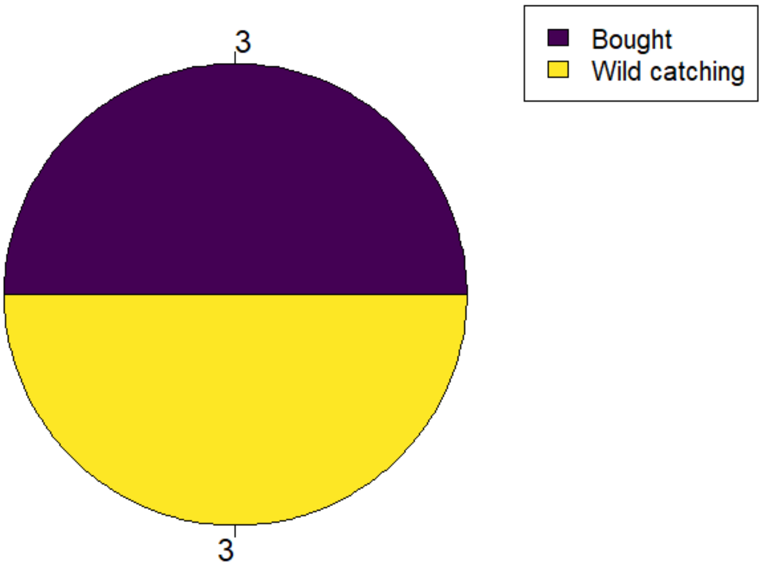

Figure 5.3: Number of beekeepers who obtained their first colony through each source in the South Pare mountains(n=6)

In Figure 5.3, it is clear how the source of the first stingless bee colony for smallholder farmers in the South Pare mountains was evenly split between buying and wild catching the colony. It is apparent how none of the bee colonies were inherited form an older generation which raises the question if this older generation of beekeepers was even present. This further supports the statement that stingless beekeeping has a longer history on Mt. Kilimanjaro than in the South Pare mountains.

5.2.2 Many cultural aspects are associated with stingless beekeeping

Because the tradition around stingless beekeeping has such a long history in the region, many cultural aspects are associated with this practice. These were most apparent on Mt. Kilimanjaro as beekeeping had a longer history here. One of the most common stories was colony abscondment (where the stingless bee colony leaves the hive) if the hive was hung next to a house where the family are not at peace. Some of the respondents also mentioned that there was another belief/taboo. If one of the women of the household who was in her menstrual cycle harvested the honey, the bees would abscond the hive. Another story was that when the beekeeper's parents or grandparents also practiced stingless beekeeping, the luck they had with beekeeping carries over to the current generation. This makes the bees less likely to abscond when manipulating the colony.

5.3 Colony abscondment as one of the main threats to stingless beekeeping

As mentioned by Kimaro et al. (2013) among others, colony abscondment is one of the main threats to stingless beekeeping at the moment. Some beekeepers even reported to be afraid of touching the colonies due to this threat. Therefore, seventeen smallholder farmers practicing stingless beekeeping on Mt. Kilimanjaro were asked for what they perceived to be the main reasons for colony abscondment and how to deal with these threats.

5.3.1 Importance of correctly choosing and maintaining the hive

Six beekeepers indicated a problem with the hive as the main reason. Two of them attributed the abscondment of the colony to a cracked or badly repaired hive. This was mostly a problem with log hives, as they cracked when the weather becomes cold. When a hive cracked, cold air was allowed to flow through the hive which made the bees abscond. A solution for a cracked hive was patching it up with a special type of rubber and metal plates. The bees would then finish the work very quickly with wax. However, to avoid abscondment of the colony due to cold airflow, reparation of the hives had to be done as soon as it was spotted.

Figure 5.4: Hive which was repaired using a metal sheet

Three other beekeepers saw the choice of a wrong material as the main reason for the abscondment of their colonies. Ideally, the wood that was used for making the colonies originates from a species in which stingless bees naturally nested. The final beekeeper said that the wood for making the hive was still too wet when the colony was transferred.

5.3.2 Predators threatening colony success

Another two beekeepers thought the main reason for colony abscondment was an attack by predators. Which predators posed a threat and why was also a question on its own. When results are ranked based on how many beekeepers named them, spiders, ants, and lizards come out on top. Spiders would build their webs around the entrance of the hive to capture and eat stingless bees, ants would invade the hive and lizards would also wait at the entrance.

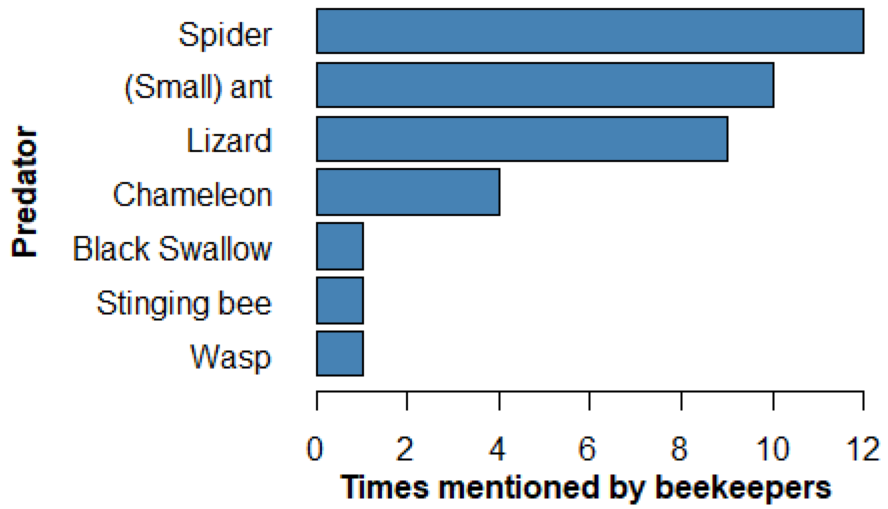

Figure 5.5: Predators for stingless bees and how many beekeepers on Mt. Kilimanjaro named them (n=18)

In some cases, the predator was only a threat in a specific case. For example, chameleons were particularly a problem when the hive was located close to a tree. The lizards on the other hand were mostly a problem when the wall next to the hive was made from a coarse material, providing grip for the lizard to hang onto.

Figure 5.6: Chameleon hunting for stingless bees

Some predators which were specified by the beekeepers on Mt. Kilimanjaro, were also mentioned in the South Pare mountains, such as ants and spiders. But the Pare beekeepers were also able to name some new species such as wood boring beetles.

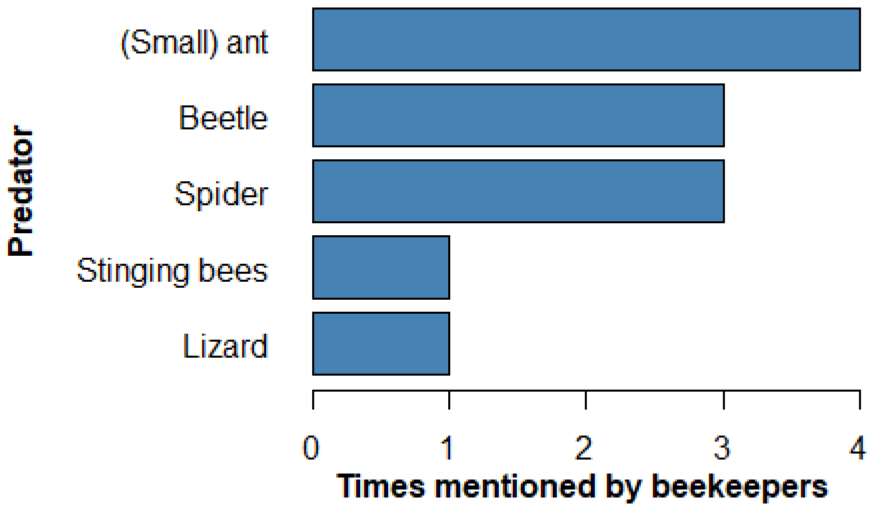

Figure 5.7: Predators for stingless bees and how many beekeepers in the South Pare mountains named them (n=5)

The countermeasures against these predators were largely the same across the two landscapes. They mostly consisted of keeping the hives clean and checking daily for any signs of attack by predators. The beekeepers all had their own way of doing this. One beekeeper even made a stick with a rag attached to the end of it to clean the hives of cobwebs.

5.3.3 Other reasons for abscondment

Two beekeepers thought their colony absconded due to an external disturbance. In both cases, this external disturbance was building activity near the hive.

Another five beekeepers referred to problems with colony multiplication as the main reason for their colonies to abscond. Three of them attributed this to bad timing for the multiplication.

Only one beekeeper saw a lack of forage as the reason for colony abscondment. However, most key informants disproved this theory. They found that a period with less flowers was possible, but a period where the bees could not find any flowers was extraordinary as bees would just venture further when no forage was available in the homegarden.

The other two beekeepers specifically stated harsh weather as the main reason for colony abscondment. As mentioned before, the timing and consequently the weather conditions had a considerable influence on the success rate of colony multiplication. This will be further explained in chapter 6.3.1.

5.4 Colony multiplication is a success influencer

The ability for beekeepers to multiply a colony on their own was one of the main factors influencing the success of the beekeeping activities. Some (12 out of 31) beekeepers on Mt. Kilimanjaro received help from a local expert (neighbour, friend, or family member) for splitting the colonies or harvesting. However, the main disadvantage of this practice was a reduction of profits because of payment to the expert.

When beekeepers could split a colony by themselves, very few of them (2 out of 16) also sold these colonies to other beekeepers. This was a missed opportunity as the sale of colonies is an excellent additional source of income since they could fetch prices between 90K and 100K TSh.

Most (71%, n=7) of the beekeepers in the South Pare mountains knew how to split a colony by themselves but none of them also sold the hives. This could be a direct point of improvement as the sale of colonies could be a successful business for beekeepers.

When asked if experts helped the beekeepers in South Pare, 2/3 of them (n=6) answered that they received help from a local expert. This raises further questions about the social structure and knowledge transfer in the South Pare mountains which will be investigated in chapter 6.3

Figure 5.8: Newly split colony. Picture by Dr. H. P. Msanga (2019)

When surveying the beekeepers about colony multiplication, many of them shared advice on how to maximise success when multiplying a colony. The most important advice was on the timing of colony multiplication. When splitting a colony, the aim should be to transfer the brood together with their queen. However, when this was not possible a new queen would be nurtured within a week. A colony which has been split could become productive within two weeks. However, it was not possible to split a colony every year as the bees would abscond. The beekeeper had to wait between two and four years to split a colony another time. Other tips which were provided concerned the practical execution of a multiplication. When splitting a colony, one beekeeper placed the brood of the hive on some sticks. This gave the bees a structure to build their nest on and it also lifted the brood from the floor so bees could walk underneath the brood. In addition, the bottom of the hive was covered in finger millet or flour. That was done since the floor could get sticky from honey that dripped onto it from breaking the pots while harvesting. A sticky floor could impede the bees from walking on the floor of the hive. Another aspect to consider when multiplying a colony was to place the new colony in the same place as the old colony, with the entrance facing in the same direction. This ensured that bees who were away from the hive when the colony was split will find their colony. The old colony had to be placed far enough from the new colony to avoid confusion. If this separation was not done properly, the bees will abscond.

5.5 Timing of the harvest

The month in which beehives on Mt. Kilimanjaro were harvested most often was December. If beekeepers were able to harvest twice a year, the second harvest was most common in June. These two moments were at the end of rainy season or at the start of dry season as shown in Table 5-3.

Table 5-3: Honey harvesting time on Mt. Kilimanjaro (n=10)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Season	Dry	Dry	Dry/Rainy	Rainy	Rainy	Dry	Dry	Dry	Dry	Rainy	Rainy	Rainy
No. of farmers harvesting	2	0	0	0	0	2	0	0	1	2	2	7

When surveying the beekeepers, some mentioned that beekeepers in the lowlands could harvest multiple times a year due to a more favourable climate. When number of yearly harvests is plotted against elevation and tested by using the Wilcoxon rank sum test to prove if the mean elevation is higher for beekeepers who can harvest only once, a p-value of 9.518e-06 is calculated. This means that beekeepers who only harvested once are on significantly higher elevations than beekeepers who harvest twice.

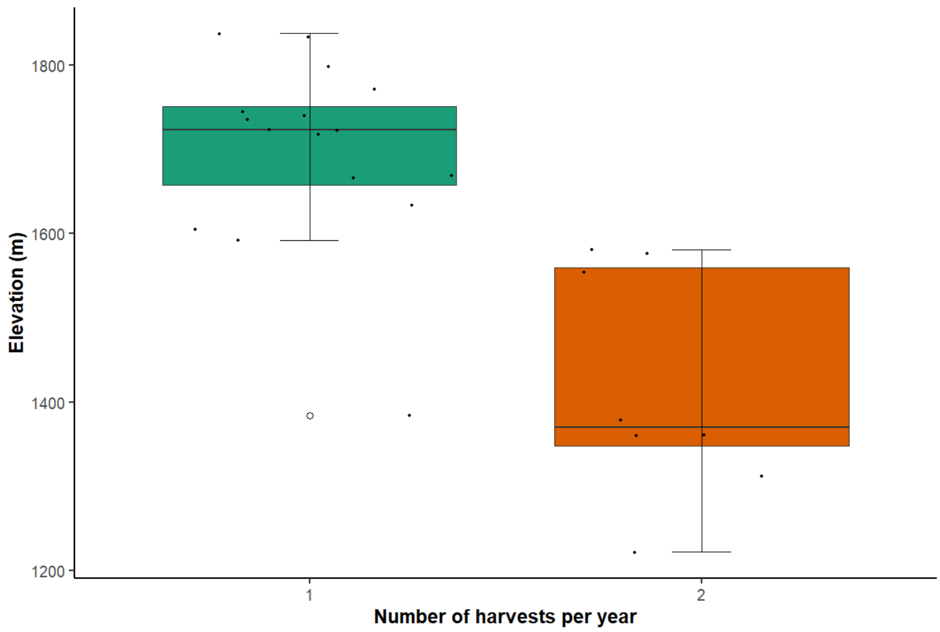

Figure 5.9: Number of yearly harvests in correlation to elevation for both Mt. Kilimanjaro and the South Pare mountains (n=25)

In the South Pare mountains, the beekeepers harvested during the dry season.

Table 5-4: Honey harvesting times in the South Pare mountains (n=4)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Season	Dry	Dry	Dry/Rainy	Rainy	Rainy	Dry	Dry	Dry	Dry	Rainy	Rainy	Rainy
No. of farmers harvesting	1	1	0	0	0	1	1	3	0	0	0	0

The beekeepers within the catchment boundaries for Southern Pare all harvested twice a year. Factors that influence this will be further elaborated in chapter 6.3.2.

5.6 Hives

5.6.1 Number of hives as a predictor for experience and skill of the beekeeper

Beekeepers on Mt. Kilimanjaro had a substantial number of hives, with 11.0±15.6 (n=28) hives being the average. This statistic was greatly influenced by their ability to multiply a colony on their own. If a beekeeper could split a colony by himself, the number rose to 13.1±16.1 (n=26). The number dropped to 9.4±16 when the beekeeper could not split a colony on their own.

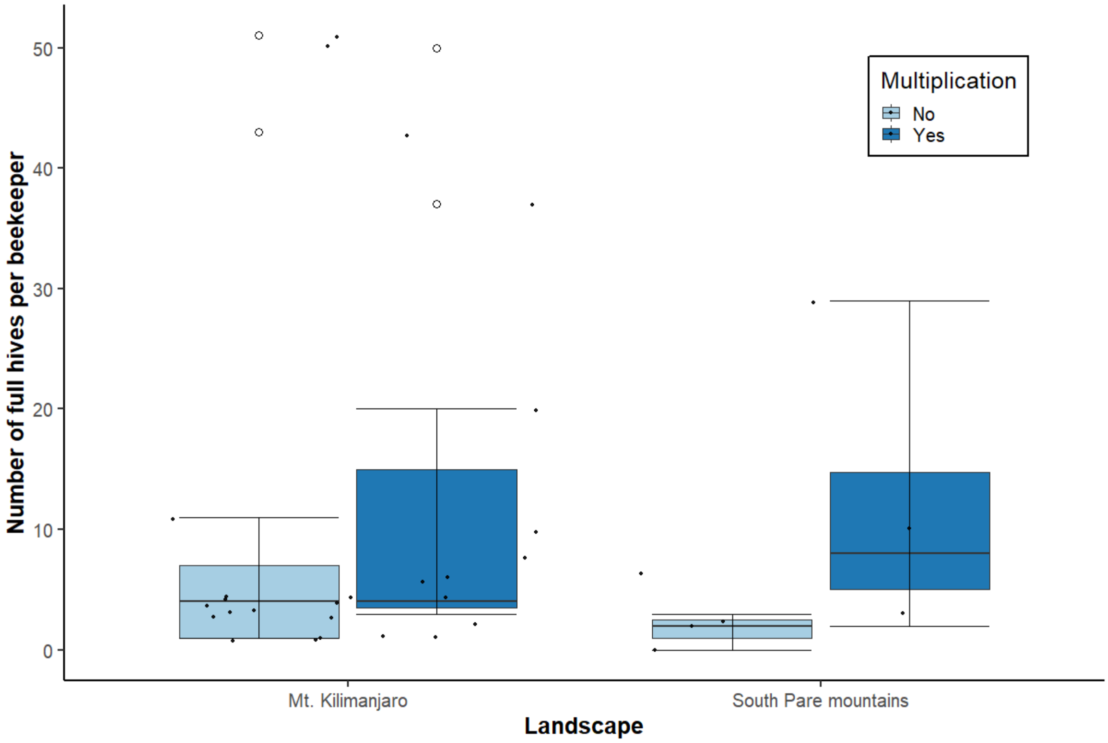

Figure 5.10: Influence of ability to multiply a colony on number of colonies (n=33)

The large standard deviation in the graph shown above (Figure 5.10) is explained by an unequal distribution of the number of hives per beekeeper which is further clarified in Figure 5.11. Only 6 of 28 beekeepers had ten or more hives, but within these six beekeepers four had more than 35 hives, with one beekeeper reaching as high as 51 hives. That made most beekeeping operations in this landscape small scale, with a few large ones. The beekeepers who had many hives were also always ambitious for getting even more hives as they were able to split them by themselves.

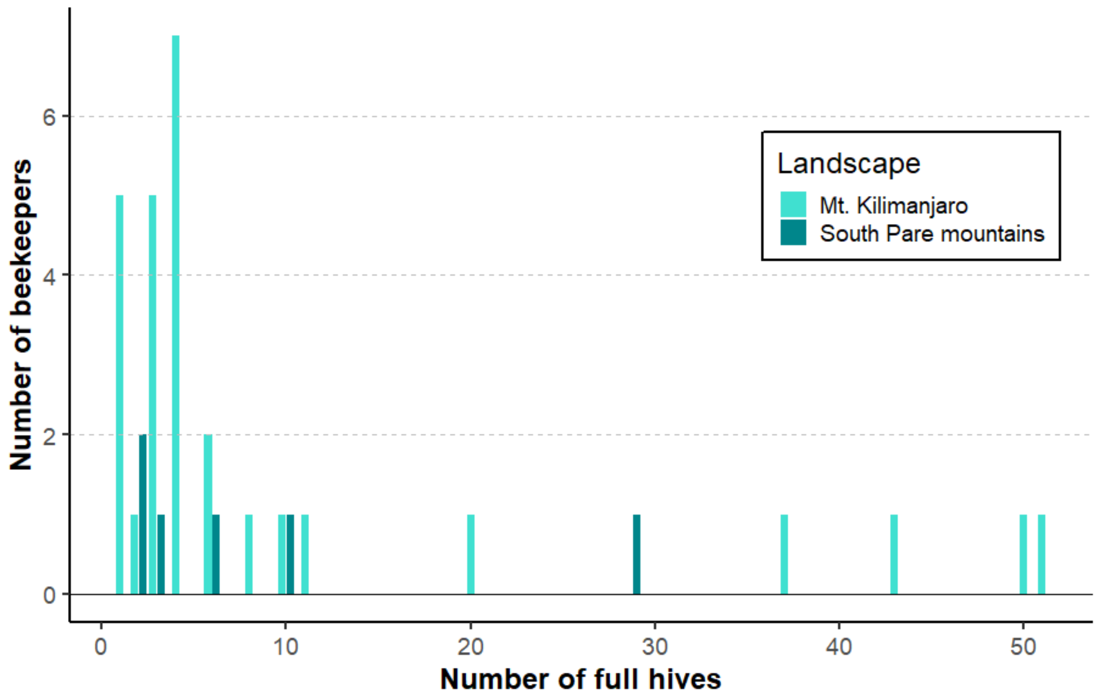

Figure 5.11: Number beekeepers possessing a number of full hives

The number of colonies was much smaller in the South Pare mountains with 7.4±10.1 (n=7) colonies per beekeeper than on Mt. Kilimanjaro. Like the situation on Mt. Kilimanjaro, this number was heavily influenced by the ability of the beekeeper to split colonies on their own. In the South Pare mountains, this influence was even more visible (seen in Figure 5.10) as beekeepers who were able to split a colony averaged 11.8±11.9 (n=7) colonies whereas beekeepers who were not able to split a colony averaged 1.7±1.53 colonies.

5.6.2 Personal preference for choice of hive type

The type of hive which was used by the beekeepers was mixed. Some (41.7%, n=12) indicated a strong preference for log hives, others (41.7%, n=12) for box hives and others (16.7%, n=12) did not have a preference at all. The beekeepers who preferred log hives attributed this mostly to the ease of harvest and lower price of the hive. Log hives were reported to be easier for the bees to build their colony in. Additionally, it was indicated that log hives produced more honey due to their natural character.

Figure 5.12: Classic log hive (left) and box hive (right), found in Mbokomu ward

The material also differed between beekeepers and landscapes. This will be discussed further in chapter 5.6.3.

5.6.3 Importance of indigenous trees as resource for hive material

As mentioned in part 5.6.3, the material of the hive was a factor that influenced the possible abscondment for the stingless bees. When the hive was of the box type, different planks could originate from different tree species. However, most hives were built from wood that was derived from the same tree species. Bees preferred a hive made from wood of a tree that they nested in naturally. These trees were specific for Mt. Kilimanjaro and the South Pare mountains respectively.

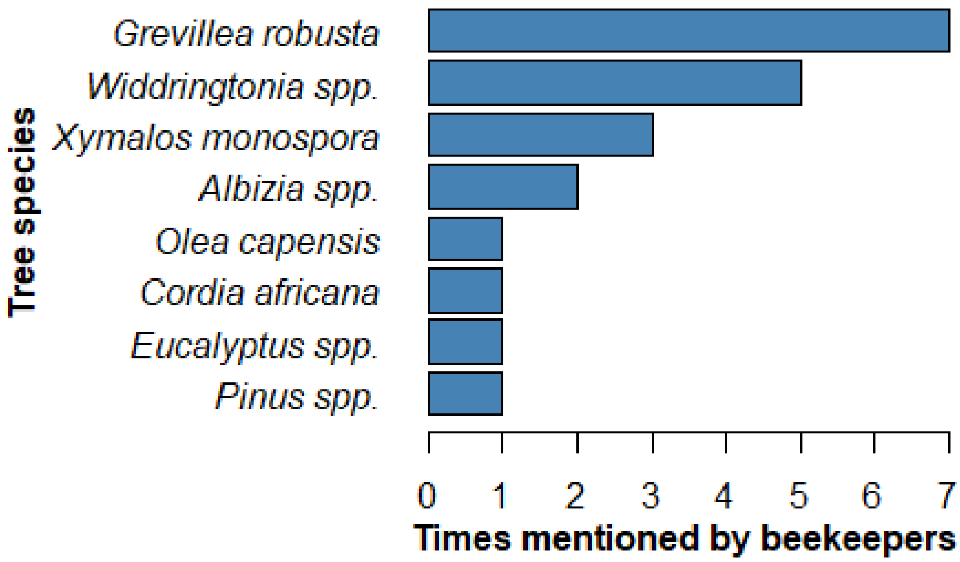

Figure 5.13: Tree species used as material for making stingless beehives on Mt. Kilimanjaro (n=12)

The trees mentioned as being suitable for making beehives were similar to those used by stingless bees for nesting in the wild. On Mt. Kilimanjaro, the trees where stingless bees had been caught in the wild were *Albizia spp., Widdringtonia spp.* and *Grevillea robusta*. All of them were mentioned three times as material for making hives by beekeepers on Mt. Kilimanjaro.

Figure 5.14: Example of a natural tree cavity in which stingless bees have nested

As expected, the trees which were used as material for building stingless beehives were different in the South Pare mountains. This was easily explained by the difference in vegetation between the regions.

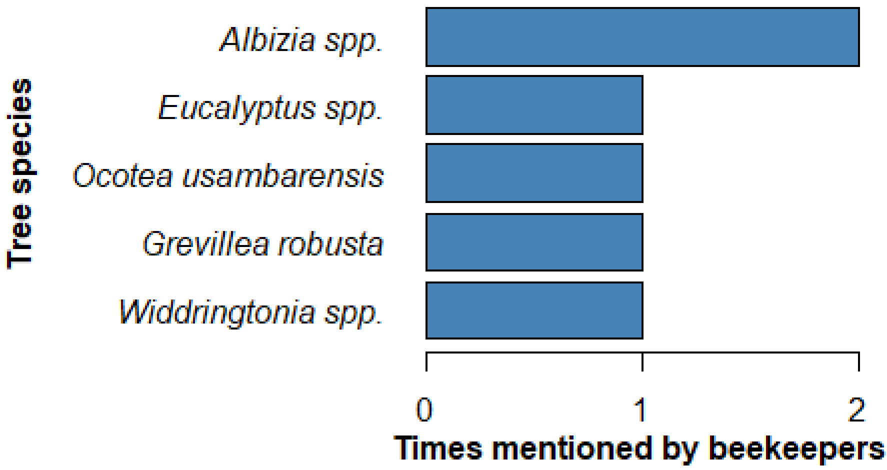

Figure 5.15: Tree species used as material for making stingless beehives in the South Pare mountains (n=3)

Some species like *Grevillea spp.* and *Widdringtonia spp.* were common for both regions, while others like *Ocotea usambarensis* were specific for the South Pare mountains due to their regional abundance.

5.7 Forage sources for stingless bees

Stingless bees use a mix of nectar and forage as a food source, which they collect from nearby plants. In the case of an agroforestry homegarden, this can be the plants in the homegarden itself or ones that are nearby. An artificial source of food for stingless bees is supplementary feeding with sugar or fruit. However, this was a rare practice for beekeepers in the region. None of the beekeepers in the South Pare mountains (n=7) reported to supplement the feed of their bees and only 3 of 22 beekeepers on Mt. Kilimanjaro supplemented the forage of their stingless bees. The supplementary feed which was supplied to the bees always consisted of a mix of banana and sugar which was administered inside the hive. The three beekeepers who employed this method were all part of the same beekeeping group, which explained their similar technique. Other beekeepers who did not supplement the feed of the bees sometimes reported that this practice would increase the yield but lower the quality. That decrease in quality would be due to a lower number of forage sources used by the bees, which would lower the medicinal powers and thus the quality of the honey.

5.7.1 Natural vegetation as a forage indicator per region

The next chapters will focus on the natural vegetation which was used by the bees as a forage source. For the part about Kibosho ward, the results of the pollen analysis will be compared to results in the article by Hemp (2006a) as the sample size was too small for a proper vegetation characterization.

5.7.2 Kibosho

The pollen types which were identified in the sample from Kibosho were assigned to a total of ten different plant families. None of these plant families had a prevalence in the sample of over 45%. Consequently, the class of predominant pollen is empty. There were some secondary pollen present in the sample. These were determined to be Cannabaceae and Poaceae pollen. In the vegetation characterisation by Hemp (2006a), these plant families were not noticed in the homegardens.

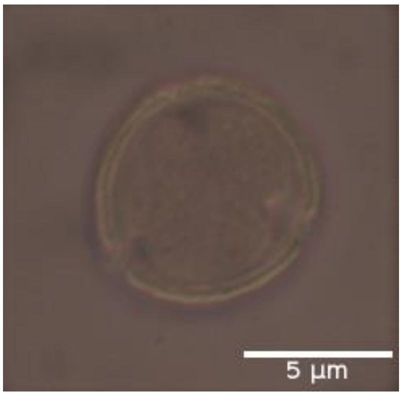

Figure 5.16: Example of Cannabaceae pollen

Pollen of the Cannabaceae family were thought to be of *Celtis africana*, a tree species which is known to occur in the area.

Table 5-5: Predominant and secondary pollen identified in the sample from Kibosho ward

Kibosho 1
Predominant pollen (>45% of pollen counted)
/
Secondary pollen (16-45% of pollen counted)
Cannabaceae
Poaceae

In this example, it was clear how the bees did not show a preference for plants in the homegarden as the most dominant pollen were all derived from plants which were only present in small percentages inside the homegarden. However, it should be noted that the abundant *Musa spp.* plants in the homegarden did not provide pollen for the bees as they are sterile. Therefore, they could not be detected in the pollen analysis. However, they were important as nectar sources for the bees. When comparing the plants which were detected to the relative abundance of these plants in the agroforestry homegardens, it was apparent how the plants which were most abundant in the homegardens were not always the ones which are used most frequently by stingless bees. An example of this were how Proteaceae was the most common tree family in the article by Hemp (2006a) with a frequency of 11.5%, but it was only counted as a minor pollen. The most common plant family in the article by Hemp (2006a) was the Asteraceae family, but in the sample it was only classified as an important minor pollen.

5.7.3 Mbokomu

Across the samples from Mbokomu ward, it was apparent how, analogue to the sample from Kibosho ward, the families of Cannabaceae, Poaceae and Asteraceae represented most of the pollen found in the samples. As in the sample from Kibosho, the main representatives for these plant families were thought to be *Celtis africana* for Cannabaceae and *Ageratum conyzoides* for Asteraceae.

When comparing these plant families to the ones which were most common in the characterisation of the homegardens, it was apparent how no plants of the Cannabaceae family were noticed during the characterisation of the homegardens (n=19). The plants which were characterised belonged mostly to the Musaceae family, but these plants were not detectable in the honey samples as mentioned before. Both Asteraceae and Poaceae were only recorded in small percentages (2.49% and 2.34% respectively).

In the article by Hemp (2006a), Asteraceae and Poaceae pollen were noted to occur as 38.9% and 0% of the homegarden respectively. Plant of the Cannabaceae family were also not documented in the article.

Table 5-6: Predominant and secondary pollen identified in samples from Mbokomu ward

Mbokomu 1	*Mbokomu 2*	*Mbokomu 3*	*Mbokomu 4*
Predominant pollen (>45% of pollen counted)			
Poaceae	Cannabaceae	Asteraceae	/
Secondary pollen (16-45% of pollen counted)			
Cannabaceae	Asteraceae	/	Cannabaceae Poaceae

Figure 5.17: Example of Asteraceae (left) and Poaceae (right) pollen

5.7.4 Kilema-Marangu

The samples from the transect in Kilema-Marangu contained pollen from families which matched the previous two regions like Asteraceae and Poaceae. In addition, the samples from Kilema-Marangu also contained pollen from Myrtaceae and Oleaceae. Plants from these families which occured in the homegardens include *Olea spp.* for Oleaceae and *Callistemon spp.* for Myrtaceae.

If the most common pollen of the pollen analysis were compared to the average composition of homegardens in this transect, it was apparent how the plant families which were present in the samples of honey were once again not represented in large numbers in the characterisation of the homegardens (n=16). Plant of the Asteraceae family were not noted, while plants of the Myrtaceae, Poaceae and Oleaceae families were only reported in small percentages (0.50%, 1.13% and 0.13% respectively)

When comparing this to the article by Hemp (2006a), plants of the Asteraceae family were reported to occur commonly (38.9%), while plants of the other families (Myrtaceae, Poaceae and Oleaceae) were not characterised at all.

Table 5-7: Predominant and secondary pollen identified in samples from Kilema-Marangu

Kilema-Marangu 1	*Kilema-Marangu 2*	*Kilema-Marangu 3*
Predominant pollen (>45% of pollen counted)		
Asteraceae	/	/
Secondary pollen (16-45% of pollen counted)		
/	Asteraceae Myrtaceae Poaceae	Asteraceae Oleaceae

Figure 5.18: Example of Myrtaceae (left) and Oleaceae (right) pollen

5.7.5 South Pare mountains

Honey samples from the South Pare mountains yielded the results which differed greatly from the results of the other samples. This was easily explained as the vegetation in the South Pare mountains was also quite different from the vegetation of Mt. Kilimanjaro where all the other samples were collected.

Table 5-8: Predominant and secondary pollen from identified in samples from the South Pare mountains

South Pare 1	*South Pare 2*
Predominant pollen (>45% of pollen counted)	
/	/
Secondary pollen (16-45% of pollen counted)	
Brassicaceae Moraceae	Brassicaceae Burseraceae Ebenaceae

One of the most striking differences from the other samples was not the occurrence of new plant families but rather the lack of Cannabaceae, Poaceae or Asteraceae pollen, which were the most common pollen on Mt. Kilimanjaro, in the two most common categories. The plant families that made up the majority of counted pollen now include Brassicaceae, Moraceae, Burseraceae and Ebenaceae. Both Brassicaceae and Ebenaceae plants were not noted in the homegarden characterisation (n=17). Moraceae and Burseraceae plants were noted, but only in small percentages (1.27% and 0.31% respectively). The article by Hemp (2006a) was not applicable here as it was focused on the Chagga homegardens of Mt. Kilimanjaro.

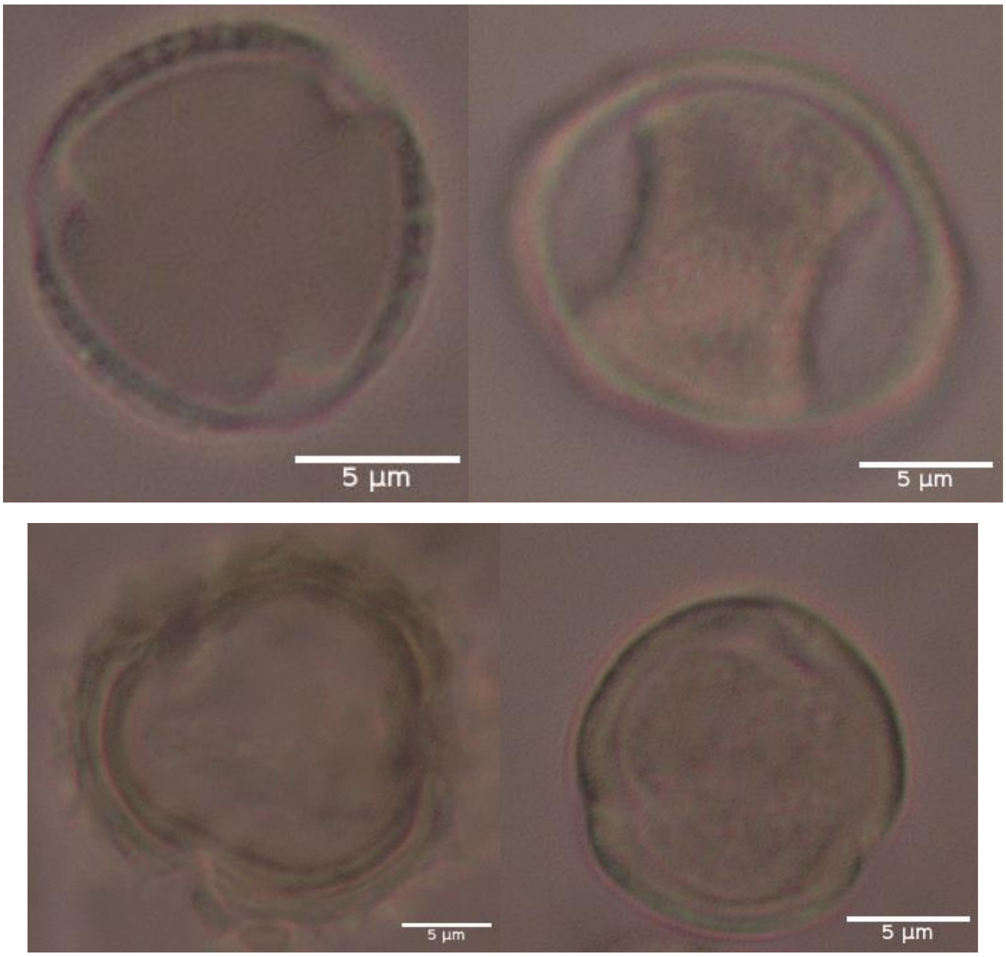

Figure 5.19: Examples of Brassicaceae (upper left), Moraceae (upper right), Burseraceae (lower left) and Ebenaceae (lower right) pollen

None of the two samples contained enough pollen from plant family to be classified as ‘Predominant pollen’, indicating that the stingless bees displayed great diversity when it came to the choice of forage sources.

6 DISCUSSION

As mentioned previously in chapter 5 about the results, this work is only the beginning of research on stingless bees in Northern Tanzania. Therefore, many conclusions remain open for discussion and further analysis. Some suggestions for that further analysis will be given in chapter 6.7.

Due to the relatively small sample size, specific conclusions are hard to make. However, this study does provide a view on some larger trends, which will be explained in the following chapters.

6.1 Surveys show a tremendous potential which is largely unfulfilled

Through the semi-directive interviews with the smallholder farmers, many of them were able to express their own opinions on stingless beekeeping which clearly exposed its strengths and weaknesses as a professional activity.

Stingless beekeeping is an activity with tremendous potential. This potential is mostly due to the low effort required to gain revenue from the activity. Smallholder farmers only have to check the hives for predators, and they are able to earn revenue from selling the honey. Stingless beekeeping also has some advantages to conventional stinging beekeeping. Beekeepers do not have to purchase protective gear due to the lack of defensive stinging behaviour of the bees. In addition, this lack of stinging behaviour also enables the smallholder farmers to practice stingless beekeeping close to their homes, making it an activity which makes it an interesting activity for families unable to leave their home for long durations of time.

6.1.1 Pollination can be further promoted as major benefit

The smallholder farmers who observed a difference in yield from their crops due to pollination, reported that coffee was one of the main crops where this difference was noticeable. This was logical as it is one of the crops that benefits most from pollination (Klein et al., 2007). This difference was most noticeable in the past when coffee cultivation was still widespread in the region. But it can also be an asset for promoting stingless beekeeping in the future for crops like avocado who benefit greatly from pollination and are rising in popularity.

In the South Pare mountains, the difference in yield due to pollination by the bees was observed by none of the smallholder farmers. Perhaps, the reason for this was the lack of coffee cultivation in this location. Many beekeepers in the South Pare mountains did not have agriculture as their main occupancy which could strengthen this effect because they are not as aware of a difference in yield as beekeepers who have agriculture as their main job. This is a missed opportunity as the difference in yield is a benefit from stingless beekeeping which can motivate more smallholder farmers in the South Pare mountains to start stingless beekeeping.

6.1.2 Current lack of involvement of women and children

The lack of involvement for women and children has been voiced as one of the main disadvantages of stinging beekeeping (Tutuba & Vanhaverbeke, 2018). This disadvantage is solved in stingless beekeeping as the bees are not harmful. However, the results presented in chapter 5.2 show that men are the main beekeeper in the vast majority of cases.

Because of the ability to place hives next to homes, stingless beekeeping also has potential for one-parent families or families with a disabled member. This fits nicely into the sustainable development goals. Stingless beekeeping provides vulnerable families with a supplementary source of income (SDG 1 and SDG 10) and improves work opportunities for women (SDG 5) (United Nations, 2015).

6.2 Awareness creation is a crucial precondition

Though stingless beekeeping possesses this potential, it currently lacks the awareness to fulfil it. Many people knew about stingless bees but were not interested in starting as a stingless beekeeper due to a large perceived investment or a lack of knowledge on how to practice it. Raising this awareness is possible in two ways.

First, it is possible to create awareness by employing government extensions officers for stingless beekeeping. Currently, trainings and information are being given to smallholder farmers about stinging beekeeping but not about the stingless kind. Even when the resources for the trainings are available, they are often implemented poorly (Kimaro et al., 2013). Therefore, this is an area where opportunities are being wasted.

The second option for raising awareness is by creating groups where local stingless beekeeping experts can exchange knowledge on their practices. That second option of local stingless beekeeping groups enjoyed the preference of most smallholder farmers who were interviewed. Smallholder farmers can spread knowledge on stingless beekeeping within these groups and even organise training events for different procedures like splitting a colony or capturing a colony in the wild. During these trainings, the specific knowledge of local experts about flowering times and harvesting periods would be an asset. These beekeeping groups can also be used in the future for collecting the stingless bee honey of all the members, checking the quality of the honey, and packaging it for sale.

6.3 Knowledge transfer is key for sustainable implementation

Older beekeepers in a community are a vital part of stingless beekeeping in the community as they could sell colonies, offer advice, and help to others. This was especially apparent in Mbokomu ward, where some beekeepers had more than 30 years of experience. These beekeepers were able to help and support other people in the village. In this way, stingless beekeeping in the village relied on their experience. In the South Pare mountains, where the history of stingless beekeeping is less extensive, this older generation was not present. This was observable in the results as the average experience of beekeepers in the region was around 5 years. Consequently, there was no older generation who could teach the techniques they used to other members of the community. This role can be fulfilled by a government extension officer, but as most members of the community were more enthusiastic about a local cooperative, this option is preferred. In the next parts, some suggestions will be given on which subjects should be part of this knowledge transfer.

6.3.1 Training on colony multiplication as one of the main necessities

Proper training on how to split a colony is crucial for making stingless beekeeping a sustainable source of income in the region. It will enable the beekeepers to develop a business from beekeeping whereas it is mostly a hobby activity up to now. This newly found business can consist of selling honey in the first place, with more hives leading to higher production increasing the export to nearby cities. While the sale of hives and colonies can be the second aspect of this business. This can be either in ready-made form consisting of a hive with a colony inside or as a service, with beekeepers travelling to other beekeepers to transfer a colony for them. The price for a colony transfer was generally between 20K and 30K TSh. Older colonies can also be sold as they can be of extra value because they can be split right away. The price for an older colony was around 150K TSh. These high prices makes colony multiplication a business opportunity on its own.

In the Pare mountains, many beekeepers could split a colony by themselves. This could be explained by stingless beekeeping not being widespread in the region, which compelled the beekeepers to learn how to split a colony by themselves. On Mt. Kilimanjaro, this was less of a necessity because many beekeepers received help from local experts due to the social structure around beekeeping in that landscape. That means the knowledge was present, but it further confirms the supposition that the social structure was not as well established as on Mt. Kilimanjaro.

6.3.1.1 Timing of colony multiplication

One of the most important variables to consider when multiplying a colony is the timing. The smallholder farmers explained that during the rainy season, the stingless bees were not able to forage as intensively as during the dry season. This meant that they could not build a colony during rainy season as the supply of food was limited. Therefore, a colony which was split during the rainy season had no food reserve and absconded. Most beekeepers chose to split the colony after they have harvested because it was more convenient as the hive was already open and the bees had to build up a food reserve anyway.

6.3.2 Harvesting preferably at the start of the dry season

Timing is very important in beekeeping as the beekeeper must ensure food security for the bees. Stingless bees do not forage in rainy conditions, but they do form perennial colonies. This made the rainy season a period where considerable amounts of resources were used, and little was refilled. When the beekeepers harvested at the start of dry season, there was no danger of the reserves running out because the bees could forage abundantly during the coming dry season. This made the start of the dry season the optimal time to harvest honey from a hive.

In addition to choosing the right time for harvesting, the number of harvests are also important as they determine the amount of honey which the beekeeper can harvest. This was demonstrated in chapter 5.1.1.1 . According to the farmers, the location of the beekeeper and thus the elevation is the main condition influencing the ability to harvest twice every year. This was proven by the statistical analysis which is summarised in Figure 5.9. In addition, the ability to harvest multiple times is probably influenced by many other factors like weather and the availability of forage. As explained in the previous paragraph, the main condition for being able to harvest twice is allowing the bees to build up a reserve to get through a period when foraging is limited. As the ability to harvest two times per year has such a large influence on the possible revenue generated by stingless beekeeping, the factors influencing the ability to harvest twice per year should be subject to further research. This will be further elaborated in part 6.7.1.

6.3.3 Transfer of knowledge about the manufacturing process of hives

Over the last few years, the beekeepers had shifted towards box hives due to a lack of technicians to make new log hives, as seen in chapter 5.6.2. The smallholder farmers described how the forests that once served as the source for these log hives were becoming increasingly protected by the government. This made them harder to get into which in turn made it harder to obtain the logs to manufacture the hives. In addition, this also required an older generation of beekeepers who have the skill needed to make a log hive.

When analysing the material of the hive, it is apparent how the smallholder farmers of both landscapes used mostly indigenous trees as the material for making the hives. This could provide an incentive to plant these indigenous species more and to avoid using the ones that are still there for other things than making stingless beehives.

6.4 Sale outside of inner circle requires quality assessment

The beekeepers mainly sold their honey to neighbours and friends which emphasizes the need to establish a structure enabling them to sell the honey to people outside their inner circle. This in turn requires a system for quality assurance. When beekeepers will be able to certify their honey, they will be able to fetch higher prices for their honey. Most beekeepers agree that this structure should be in the form of a local cooperative as previous government structures for stinging beekeeping have had varying degrees of success in the past. Within this cooperative, the beekeepers could check the quality of the honey, pack it, label it, and sell it in town or even abroad. Currently, the main constraints are difficulties with checking the quality of the honey to guarantee good quality.

The focus of smallholder farmers on quality assurance, which is described in chapter 5.1.1.3, proves that stingless bee honey is a product which is often adulterated with stinging bee honey or water. This risk of adulteration is due to the high value and low demand of genuine stingless bee honey. While local methods are sufficient for checking the quality of small batches bought locally, the market needs proper standardised methods for checking the quality of stingless bee honey. The development of these methods is outside the scope of this study and will be further discussed in chapter 6.7.6.

6.5 Identification of forage sources

The small number of beekeepers who supplement the feed of the stingless bees means that almost all the food for the bees is obtained by foraging trips. Therefore, the natural flowering vegetation in the area is the major contributor to forage for the stingless bees.

6.5.1 Pollen analysis

It is clear from the pollen analysis that a substantial portion of pollen found in the samples originates from smaller flowers and grasses. This is in line with other articles like the one by Ramírez-Arriaga et al. (2018) where pollen analysis was performed for pollen collected by stingless bees in Mexico. These smaller herbs and grasses were not described in the vegetation analysis. This could be due to their lower remarkability than larger plants like trees and shrubs. Smaller herbs and grasses mostly occur in smaller patches outside the homegardens, where competition with other insects might be lower than in the larger trees in the homegarden. The smaller size of stingless bees could also play a role here as this could provide a competitive advantage over larger insects and birds.

For larger plants like trees and shrubs, the abundance of pollen in the samples was not reflected in the abundance of that plant family in the homegardens. This means that the stingless bees frequently visited trees and shrubs in the nearby forest or the lowlands. An example of one of the most dominant plant families in the honey samples form Mt. Kilimanjaro was Cannabaceae. The main representative of this plant family is thought to be *Celtis africana*. This tree was very rarely seen in the homegardens, and it was not described in the vegetation of the homegardens which means that the bees obtained these pollen in the forest or in the lowlands. Additionally, the tree could be promoted in the future as it is indigenous and provides forage for the stingless bees.

In conclusion, smaller flowers and grasses are as important for stingless bees as larger trees. This is in line with the findings of other studies performing pollen analysis on stingless bee honey like the one by Ramírez-Arriaga et al. (2018) and it serves as a reminder how trees and shrubs are not the only plants to consider when planting in a homegarden. However, that does not mean that trees and shrubs should be left behind in future research as they still make up a substantial part of the forage for the stingless bees.

6.5.2 Choice for pollen analysis in honey

The method which was used in this research is a pollen analysis of the honey produced by the bees. This honey was bought from stingless beekeepers as harvesting fresh honey was not a possibility due to the surveys being timed outside of harvesting periods. However, all honey samples were harvested recently (Max. 6 months ago) and were kept in a clean plastic container by the beekeeper. The honey was relatively easy to obtain as most smallholder farmers saw stingless bee honey as a method of generating income. Therefore, they sold it at the going price. Due to the excellent preservation of pollen in honey, rotting of the pollen never was a concern.

Many other methods also exist for discovering which forage sources are used by the stingless bees, with the simplest method being to observe the bees while they forage. Notes can be taken for which plants they visit and how frequent these visits occur. However, this method is time consuming, and the stingless bees can forage on plants outside of the view of the observer. In addition, the method lacks data from months when the observer was not present at the site. This is especially important for stingless bees as they form perennial colonies. This establishes the choice for pollen analysis.

The choice was made to identify pollen present in the honey from stingless bees, but other methods are to collect fresh pollen from returning foragers or to analyse the pollen present in the pollen storage of the nest. Collecting fresh pollen from bees or from the storage was eliminated as a possible method because most smallholder farmers were very reluctant to manipulate the stingless bees or their nest. When analysing the honey, the bees do not need to be manipulated. Furthermore, the method where pollen are collected from bees only captures pollen which were collected by the stingless bees during the sampling period. In contrast, pollen analysis in honey captures pollen from the entire season.

Performing pollen analysis on honey samples also provided the advantage that pollen are very well preserved in the honey. This proved especially useful as most smallholder farmers were in rural areas. Honey samples can contain pollen from wind pollinators or pollen which stuck to the bees but were not part of their forage. But due to the disadvantages of other methods, pollen analysis of honey samples was chosen. It provides a good overview of plants which were used as forage by the bees and the method is practically feasible in a rural environment.

6.6 Decision support app

6.6.1 Current capabilities

The “decision support app” provides a functional starting point. It can be used by beekeepers and researchers to compare the forage availability of homegardens. That can be helpful to investigate the suitability of other homegardens or in regions where stingless beekeeping is not currently practiced. The application can also serve as a physical example of the progress in research surrounding stingless beekeeping. This can motivate policy makers and even investors to believe and possibly invest in the project.

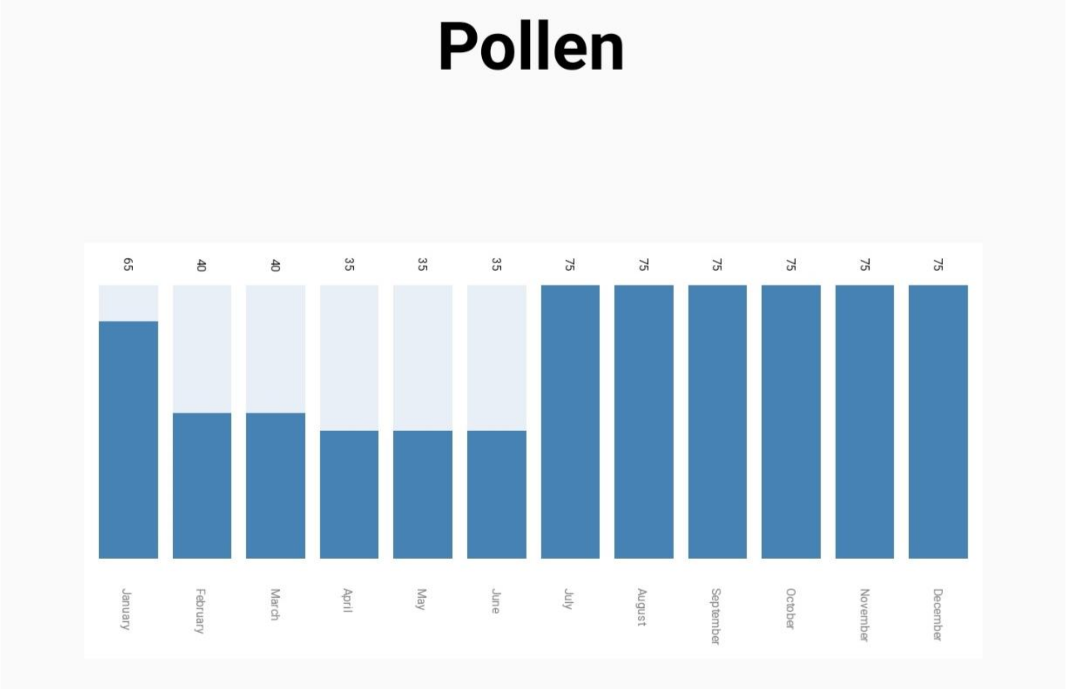

Figure 6.1: Example of pollen availability in homegarden

When the composition of the homegarden is entered into the application. The resulting graph for pollen is shown above in Figure 6.1. The graph for nectar availability is shown in Figure 6.2. Each column represents the relative availability of forage in a certain month of the year. The number on top of the column represents a score for how much forage is available. This score is calculated by making a sum of the relative abundance of plants in the homegarden which flower during that month. Other screenshots and larger versions of the figures provides here are presented in Appendix E.

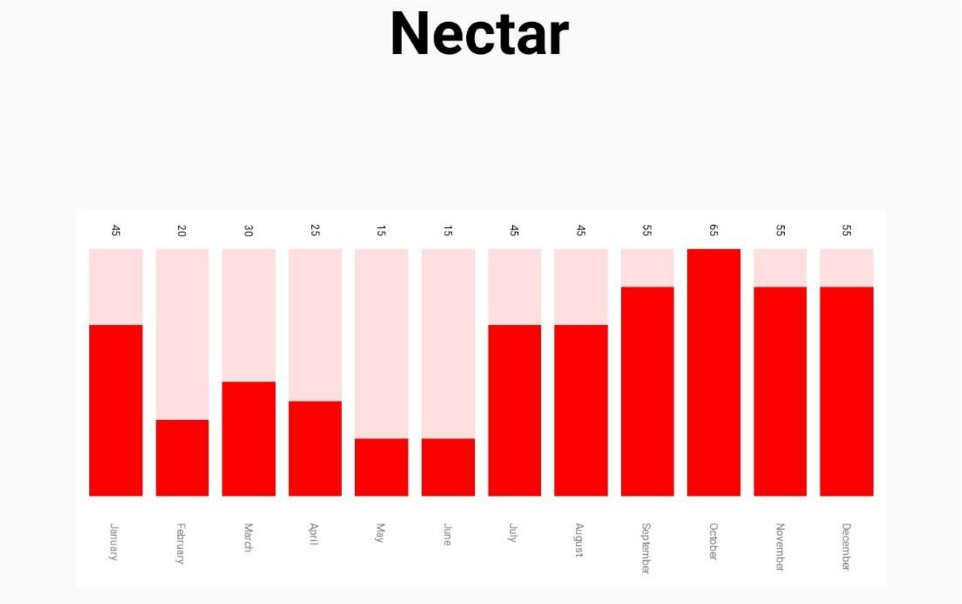

Figure 6.2: Example of nectar availability in homegarden

The choice for the platform was deliberate as more people obtain smartphones in rural areas. That makes it vital to follow this transition by building an application fit for these devices. In addition, the application does not rely on internet access as this is often hard to obtain in these remote areas.

6.6.2 Potential for future development

As mentioned above in section 6.6.1, the application provides a functional starting point but needs further development to provide real use for the smallholder farmers. That development starts with the expansion of the database of plants. As the agroforestry homegardens are a diverse system, they contain many different species of plants. However, only a few of them are included in the application as data is currently limited on this topic. In addition, there is a need for a categorization of the relative importance of the plants. Right now, all nectar and pollen sources are categorised as nectar or pollen sources, but their relative importance was not measured. That could change in the future by conducting research on the nectar- and pollen production of every plant. This would enable developers of the application to classify the sources based on their importance and to provide a more accurate representation accordingly.

In a later phase, the functionality of the application can be expanded to provide more features. An example of a feature that could be part of a future version is the provision of ideas for improvement of the homegarden to the user. When the application detects a low availability of nectar or pollen during that period of the year, it can suggest a plant which flowers in that period and provides the stingless bees with forage. Another example of an additional feature is that the application can be expanded to show multiple graphs at once. This will allow smallholder farmers and researchers to compare different homegardens more easily.

6.7 Potential for further research

Stingless beekeeping is an activity that undeniably has enormous potential, as has been illustrated in previous chapters. This potential is now mostly untouched as many researchers are unfamiliar with stingless beekeeping. Smallholder farmers do know about the potential, and they were always very enthusiastic about the idea of researching stingless bees instead of stinging honeybees. That enthusiasm has served as a great motivation throughout this thesis. However, as this is a reconnaissance study on stingless beekeeping in the region, the farmers often provided more questions than answers. Therefore, an outlook on the next steps for research on this topic is vital for them.

6.7.1 Measuring influence of external factors on honey production

During the surveys with beekeepers, the quantity of honey produced by the stingless bees was an essential characteristic. Beekeepers revealed that the production of honey is variable, with some years more productive than others. Especially weather is a key factor when considering honey production by stingless bees. Stingless bees do not forage when it rains, but weather also has an influence on the flowering phenology of plants. Consequently, honey production drops due to multiple factors when weather conditions are not ideal. In addition to weather, farmers have mentioned that other factors such as altitude can also possibly influence the production of honey. Therefore, future research can provide clarification on which external factors influence production and how they influence it. To provide a global overview of the honey production throughout the year, this future research should surely consist of a longer field campaign as the bees forage during the entire year.

Within this future research, another factor which can be analysed is the influence of elevation, landscape geomorphology and weather conditions among other factors on the ability for beekeepers to harvest multiple times. These factors will be linked to the factors influencing production as the ability to harvest multiple times is a result of increased production.

6.7.2 Documenting foraging strategies of stingless bees in AGF homegardens

This thesis has provided a first look on the plant species which are most frequently used by stingless bees as forage sources, but it lacks a description of the strategies employed by the bees to get to these forage sources. Therefore, these strategies and the influence of external factors like climate and presence of competition can be subject to further investigation.

6.7.3 Study of rich culture surrounding stingless beekeeping

The culture surrounding stingless beekeeping is especially rich in regions where stingless beekeeping has been practiced for many generations, such as on Mt. Kilimanjaro. This rich culture is a subject that deserves to be investigated on its own as cultural aspects need to be taken into consideration when informing people about stingless beekeeping. However, this investigation falls outside of the scope of this thesis as this is more of a sociological subject.

6.7.4 Repetitive pollen analysis over time

Due to practical limitations and a short field campaign, the pollen analysis was done on honey samples which were previously collected by the smallholder farmers during a harvesting period. The evolution food sources used by the stingless bees over time can be investigated as it has been done previously by Ramírez-Arriaga et al. (2018) for Mexican stingless bees.

6.7.5 Identification of stingless bee species

Every species of stingless bees has distinct preferences for the species they prefer to forage on. Consequently, articles about foraging preferences in stingless bees like the one by Ramírez-Arriaga et al. (2018) in Mexico or by Ferreira & Absy (2017) in Brazil first determine the stingless bee species which is investigated. Due to the limited knowledge about stingless bee species in Africa and the specialised knowledge required for determining the species, stingless bee species were not individually identified. That identification can serve as the subject for future research.

6.7.6 Quality assessment of stingless bee honey

As mentioned previously in chapter 5.1.1, the local market for stingless bee honey still currently exceeds the supply. However, this market could get saturated over time when more smallholder farmers start practicing stingless beekeeping and beekeepers are able to obtain higher yields. In addition, the beekeepers indicated that the prices for stingless bee honey are up to 10K Tsh higher per litre in large towns and cities. To be able to export the stingless bee honey to these larger markets, the beekeepers need to able to guarantee the quality of their honey. Many beekeepers claimed that the honey from their region was superior in quality to other regions for several reasons. If this can be proven scientifically, it would offer a competitive advantage to these beekeepers.

The requirements for a certification of stingless bee honey have recently been published in by Tanzanian Bureau of Standards (TBS) in TZS1966:2020. However, no organization has been certified for these quality requirements so far. For that reason, further research on this topic can check if the honey provided by the beekeepers matches the quality standards specified by TBS. From this laboratory analysis, practical recommendations can be made to the beekeepers on how to ensure the quality of their honey.

6.7.7 Marketing other hive products

Currently, the sale of stingless bee honey is the only revenue generating activity derived from stingless bees. However, honey is not the only useful hive product of stingless bees. As already mentioned in the literature review of this thesis; propolis, pollen and wax can also be sold. More research should be conducted on the properties and health advantages of these hive products to improve their position in the market. This would make stingless beekeeping even more profitable. In addition, it would make the revenue generated through the activity steadier, even when honey production is low.

7 CONCLUSION

Agroforestry homegardens like the Chagga system have long provided people in Northern Tanzania with valuable resources (Soini, 2005a). The Chagga system has even gained international recognition as a global example for sustainability, but they are under pressure (Kitalyi et al., 2013). The homegardens are mainly composed of coffee and banana, but dropping coffee prices in combination with population strain have forced farmers to intensify their production which in turn has led to land scarcity (Cooper et al., 1995; Maitima et al., 2009; Soini, 2005b; Viswanath & Lubina, 2017). This limitation has driven farmers to diversify their production and search for additional sources of income (Paavola, 2008).

An example for that diversification is stingless beekeeping. It provides the farmers with an incentive to revitalise natural vegetation which serves as a forage source for the bees (Macharia et al., 2007; Sinyangwe et al., 2010). Another advantage is that stingless beekeeping will not be affected by the low coffee prices. The high-risk perception of beekeeping and the lack of involvement of women and youth have been voiced by local farmers in the past as being one of the main disadvantages of stinging beekeeping (Tutuba & Vanhaverbeke, 2018). Stingless beekeeping is an alternative which is not faced by those problems due to a lack of functional stinger. This makes stingless beekeeping suited for a use close to settlements and for one-parent families or families with a disabled person (Slaa et al., 2000). This fits in with the sustainable development goals, as stingless beekeeping has potential to improve work opportunities for women (SDG 5) and to provide vulnerable families with an additional source of income (SDG1 and SDG10).

The method of stingless beekeeping as a source of sustainable livelihoods has been explored with promising results in the neotropics (Jaffé et al., 2015). However, it has been very scarcely documented in Africa even though locals have built up a lot of knowledge over the years (Kidane et al., 2021; Njau et al., 2010).

Therefore, this study has served as a reconnaissance study in the field, documenting what is already present and providing suggestions for further research. Stingless beekeeping is an activity with an undeniable potential. It can help local farmers as a reliable source of additional income whilst requiring little time commitment. But this study has found that it currently faces many challenges. Some of which are practical in nature like properly protecting the stingless bees against predators, but the fundamental issues are structural.

The main structural challenges which are faced by stingless beekeeping today are a lack of awareness and proper training. The former of which can only be solved by convincing smallholder farmers of the potential of the activity and debunking myths like the large perceived risk. On the other hand, the latter can be solved by providing aspiring stingless beekeepers with training from more experienced members of the community. Those experienced members of the community should be empowered to share their knowledge and skill with others as they are vital for transferring the knowledge necessary for spreading the knowledge on stingless beekeeping.

Foraging potential in agroforestry homegardens was a particular focus for this study as knowing what the stingless bees use as forage is a major step in the optimalisation of stingless beekeeping in the region. This was achieved through pollen analysis of the honey and yielded similar results as in pollen analysis studies in other parts of the world like the one by Ramírez-Arriaga et al. (2018) which was conducted in Mexico. The pollen analysis showed that a substantial fraction of the pollen inside of the honey were derived from smaller herbs and grasses. This means that stingless beekeepers should also consider these smaller plants when determining the composition of their homegarden.

As a reconnaissance study, part of the focus of this thesis has been on providing opportunities for further research. From the interviews with smallholder farmers practicing stingless beekeeping, it was apparent how the implementation of a quality assurance system is vital for further improving profitability. Where stingless bee honey is mostly sold to neighbours and friends right now, a quality assurance system would enable beekeepers to sell their honey in larger towns and cities. As the quality standard is already specified by TBS, the comparison of produced stingless bee honey with these standards provides an interesting point for further research.

References

Agrawala, S., Moehner, A., Hemp, A., Aalst, M. van, Hitz, S., Smith, J., Meena, H., Mwakifwamba, S. M., Hyera, T., & Mwaipopo, O. U. (2003). *Development and climate change in Tanzania: Focus on Mount Kilimanjaro* [Working Paper]. Organisation for Economic Co-operation and Development. http://www.taccire.sua.ac.tz/handle/123456789/442

Almutairi, S., Eapen, B., Chundi, S. M., Akhalil, A., Siheri, W., Clements, C., Fearnley, J., Watson, D. G., & Edrada-Ebel, R. (2014). New anti-trypanosomal active prenylated compounds from African propolis. *Phytochemistry Letters*, *10*, 35–39.

Astolfi, G., Gonçalves, A. B., Menezes, G. V., Borges, F. S. B., Astolfi, A. C. M. N., Matsubara, E. T., Alvarez, M., & Pistori, H. (2020). POLLEN73S: An image dataset for pollen grains classification. *Ecological Informatics*, *60*, 101165.

Ávila, S., Beux, M. R., Ribani, R. H., & Zambiazi, R. C. (2018). Stingless bee honey: Quality parameters, bioactive compounds, health-promotion properties and modification detection strategies. *Trends in Food Science & Technology*, *81*, 37–50.

Bankova, V. S., Castro, S. L. D., & Marcucci, M. C. (1999). *Propolis: Recent advances in chemistry and plant origin*. 14.

Base de donnée palynologique de référence de l'ISEM. (n.d.). Retrieved October 20, 2021, from https://data.oreme.org/palyno/palyno_gallery#photo_taxon_list

Bertelli, D., Papotti, G., Bortolotti, L., Marcazzan, G. L., & Plessi, M. (2012). 1H-NMR Simultaneous Identification of Health-Relevant Compounds in Propolis Extracts. *Phytochemical Analysis*, *23*, 260–266.

Biesmeijer, J. C., & Slaa, E. J. (2004). Information flow and organization of stingless bee foraging. *Apidologie*, *35*, 143–157.

Biesmeijer, J. C., & Slaa, E. J. (2006). The structure of eusocial bee assemblages in Brazil. *Apidologie*, *37*, 240–258.

Biluca, F. C., Della Betta, F., de Oliveira, G. P., Pereira, L. M., Gonzaga, L. V., Costa, A. C. O., & Fett, R. (2014). 5-HMF and carbohydrates content in stingless bee honey by CE before and after thermal treatment. *Food Chemistry*, *159*, 244–249.

Bradbear, N. (2009). Bees and their role in forest livelihoods A guide to the services provided by bees and the sustainable harvesting, processing and marketing of their products. *Production and Trade of Beeswax (Chapter 10), FAO*.

Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. a. B., Rylands, A. B., Konstant, W. R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., & Hilton-Taylor, C. (2002). Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology*, *16*(4), 909–923.

Buchanan, G. M., Donald, P. F., & Butchart, S. H. M. (2011). Identifying Priority Areas for Conservation: A Global Assessment for Forest-Dependent Birds. *Plos One*, *6*(12), e29080.

Burgess, N. D., Butynski, T. M., Cordeiro, N. J., Doggart, N. H., Fjeldså, J., Howell, K. M., Kilahama, F. B., Loader, S. P., Lovett, J. C., Mbilinyi, B., Menegon, M., Moyer, D. C., Nashanda, E., Perkin, A., Rovero, F., Stanley, W. T., & Stuart, S. N. (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological Conservation*, *134*(2), 209–231.

Butz, R. J. (2013). Changing land management: A case study of charcoal production among a group of pastoral women in northern Tanzania. *Energy for Sustainable Development*, *17*(2), 138–145.

Campbell, D. R., & Motten, A. F. (1985). The Mechanism of Competition for Pollination between Two Forest Herbs. *Ecology*, *66*, 554–563.

Campos, J. F., dos Santos, U. P., da Rocha, P. dos S., Damiao, M. J., Perrella Balestieri, J. B., Lima Cardoso, C. A., Paredes-Gamero, E. J., Estevinho, L. M., Souza, K. de P., & dos Santos, E. L. (2015). Antimicrobial, Antioxidant, Anti-Inflammatory, and Cytotoxic Activities of Propolis from the Stingless Bee *Tetragonisca fiebrigi* (Jatai). *Evidence-Based Complementary and Alternative Medicine*, *2015*, 296186.

Carroll, T., & Kinsella, J. (2013). Livelihood improvement and smallholder beekeeping in Kenya: The unrealised potential. *Development in Practice*, *23*, 332–345.

Chakraborty, P., Ghosal, K., Sarkar, E., & Gupta-Bhattacharya, S. (2016). Atmospheric Pollen Grains of a Suburban Area near India-Bangladesh Border with Reference to their Allergenic Potential and Probable Effect on Asthma-Related Hospital Admission. *Current Science*, *111*.

Charles, R., Munishi, P., & Nzunda, E. (2013). Agroforestry as Adaptation Strategy under Climate Change in Mwanga District, Kilimanjaro, Tanzania. *International Journal of Environmental Protection*, *3*, 29–38.

Chidi, H., & Odo, E. (2017). *Meliponiculture for Sustainable Economy*.

Chuttong, B., Chanbang, Y., & Burgett, M. (2014). Meliponiculture. *Bee World*, *91*(2), 41–45.

Cooper, P. J. M., Leakey, R. R. B., Rao, M. R., & Reynolds, L. (1995). *Agroforestry and the Mitigation of Land Degradation in the Humid and Sub-humid Tropics of Africa*. 56.

Crane, E. (1992). The Past and Present Status of Beekeeping with Stingless Bees. *Bee World*, *73*, 29–42.

de Bruijn, L. L. M., & Sommeijer, M. J. (1997). Colony foraging in different species of stingless bees (Apidae, Meliponinae) and the regulation of individual nectar foraging. *Insectes Sociaux*, *44*, 35–47.

Eardley, C. D. (2004). *Taxonomic revision of the African stingless bees (Apoidea: Apidae: Apinae: Meliponini)*.

Eardley, C. D., Kuhlmann, M., & Pauly, A. (2010). *The Bee Genera and Subgenera of sub-Saharan Africa* | (Vol. 7). Abc Taxa. http://www.abctaxa.be/volumes/vol-7-bees

Eardley, C., & Kwapong, P. (2013). Taxonomy as a Tool for Conservation of African Stingless Bees and Their Honey. In P. Vit, S. R. M. Pedro, & D. Roubik (Eds.), *Pot-Honey: A legacy of stingless bees* (pp. 261–268). Springer.

Engels, W., & Imperatriz-Fonseca, V. L. (1990). Caste Development, Reproductive Strategies, and Control of Fertility in Honey Bees and Stingless Bees. In W. Engels (Ed.), *Social Insects: An Evolutionary Approach to Castes and Reproduction* (pp. 167–230). Springer.

Ferreira, M. G., & Absy, M. L. (2017). Pollen analysis of honeys of *Melipona* (Michmelia) *seminigra merrillae* and *Melipona* (Melikerria) *interrupta* (Hymenoptera: Apidae) bred in Central Amazon, Brazil. *Grana*, *56*(6), 436–449.

Finch, J., Marchant, R., & Courtney Mustaphi, C. J. (2017). Ecosystem change in the South Pare Mountain bloc, Eastern Arc Mountains of Tanzania. *The Holocene*, *27*(6), 796–810.

Friis, L., & Lawesson, J. E. (1993). Altitudinal zonation in the forest tree flora of northeast tropical Africa. *Opera Botanica*, *121*, 125–127.

Global Pollen Project. (n.d.). Retrieved October 20, 2021, from https://globalpollenproject.org/

Gosling, W. D., Miller, C. S., & Livingstone, D. A. (2013). Atlas of the tropical West African pollen flora. *Review of Palaeobotany and Palynology*, *199*, 1–135.

Hall, J., Burgess, N. D., Lovett, J., Mbilinyi, B., & Gereau, R. E. (2009). Conservation implications of deforestation across an elevational gradient in the Eastern Arc Mountains, Tanzania. *Biological Conservation*, *142*(11), 2510–2521.

Hamisi, I. (2016). *Diversity, status and threats to stingless bees (Apidae: Meliponini) of Ipembampazi Forest Reserve, Tabora—Tanzania* [Sokoine University of Agriculture]. http://www.suaire.sua.ac.tz/handle/123456789/1533

Harder, L. D. (1985). Morphology as a Predictor of Flower Choice by Bumble Bees. *Ecology*, *66*, 198–210.

Hemp, A. (2006a). The banana forests of Kilimanjaro: Biodiversity and conservation of the Chagga homegardens. *Biodiversity and Conservation*, *15*, 1193–1217.

Hemp, A. (2006b). Continuum or zonation? Altitudinal diversity patterns in the forests on Mt. Kilimanjaro. Plant Ecology, 184(1), 27-42. *Plant Ecology*, *184*, 27–42.

Hemp, A., & Hemp, C. (1999). *Environment And Worldview: The Chaga Homegardens Part I: Ethnobotany And Ethnozoology* (pp. 235–303).

Henske, J., Krausa, K., Hager, F. A., Nkoba, K., & Kirchner, W. H. (2015). Olfactory associative learning in two African stingless bee species (*Meliponula ferruginea* and *M-bocandei*, Meliponini). *Insectes Sociaux*, *62*, 507–516.

Hrncir, M., & Maia-Silva, C. (2013). On the Diversity of Foraging-Related Traits in Stingless Bees. In P. Vit, S. R. M. Pedro, & D. Roubik (Eds.), *Pot-Honey: A legacy of stingless bees* (pp. 201–215). Springer.

Hubbell, S. P., & Johnson, L. K. (1978). Comparative Foraging Behavior of Six Stingless Bee Species Exploiting a Standardized Resource. *Ecology*, *59*, 1123–1136.

Huntington, H. P. (2000). Using Traditional Ecological Knowledge in Science: Methods and Applications. *Ecological Applications*, *10*(5), 1270–1274.

Ichinose, Y., Higuchi, H., Kubo, R., Nishigaki, T., Kilasara, M., Shinjo, H., & Funakawa, S. (2020). Adaptation of farmland management strategies to maintain livelihood by the Chagga people in the Kilimanjaro highlands. *Agricultural Systems*, *181*, 102829.

Inoue, T., Sakagami, S. F., Salmah, S., & Yamane, S. (1984). The Process of Colony Multiplication in the Sumatran Stingless Bee *Trigona* (Tetragonula) *laeviceps*. *Biotropica*, *16*, 100–111.

International Coffee Organization. (2018). *Prices paid to growers in exporting countries*. http://www.ico.org/historical/1990%20onwards/PDF/3a-prices-growers.pdf

Jaffé, R., Pope, N., Carvalho, A. T., Maia, U. M., Blochtein, B., de Carvalho, C. A. L., Carvalho-Zilse, G. A., Freitas, B. M., Menezes, C., de Fátima Ribeiro, M., Venturieri, G. C., & Imperatriz-Fonseca, V. L. (2015). Bees for Development: Brazilian Survey Reveals How to Optimize Stingless Beekeeping. *PLOS ONE*, *10*, e0121157.

Jalil, M. A. A., Kasmuri, A. R., & Hadi, H. (2017). Stingless Bee Honey, the Natural Wound Healer: A Review. *Skin Pharmacology and Physiology*, *30*(2), 66–75.

Jeil, E. B., Abass, K., & Segbefia, A. Y. (2020). Challenges to sustaining beekeeping livelihoods in Ghana. *GeoJournal*.

Kajobe, R. (2007). Botanical sources and sugar concentration of the nectar collected by two stingless bee species in a tropical African rain forest. *Apidologie*, *38*, 110–121.

Kajobe, R. (2013). Important Bee Plants for African and Other Stingless Bees. In P. Vit, S. R. M. Pedro, & D. Roubik (Eds.), *Pot-Honey: A legacy of stingless bees* (pp. 315–335). Springer.

Karikari, A., & Kofi, K. (2007). A survey of Indigenous Knowledge of Stingless Bees (Apidae: Meliponini) in the Central Region of Ghana. *Journal of the Ghana Science Association.*, *9*.

Kasina, M., Mburu, J., Kraemer, M., & Holm-Mueller, K. (2009). Economic Benefit of Crop Pollination by Bees: A Case of Kakamega Small-Holder Farming in Western Kenya. *Journal of Economic Entomology*, *102*, 467–473.

Kidane, A. A., Tegegne, F. M., & Tack, A. J. M. (2021). Indigenous knowledge of ground-nesting stingless bees in southwestern Ethiopia. *International Journal of Tropical Insect Science*.

Kimaro, J., Liseki, S., Mareale, W., & Mrisha, C. (2013). Enhancing rural food security through improved beekeeping in Northern Tanzania. *Livestock Research for Rural Development*, *25*.

Kinati, C., Ejeta, T., Debele, K., & Tolosa, T. (2012). Opportunities and challenges of honey production in Gomma district of Jimma zone, South-west Ethiopia. *The Journal of Agricultural Education and Extension.*, *4*, 85–91.

Kitalyi, A., Otsyina, R., Wambugu, C., & Kimaro, D. (2013). *FAO Characterisation of Global Heritage Agroforestry Systems in Tanzania and Kenya*. 82.

Klein, A.-M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences*, *274*, 303–313.

Kraus, F. B., Weinhold, S., & Moritz, R. F. A. (2008). Genetic structure of drone congregations of the stingless bee *Scaptotrigona mexicana*. *Insectes Sociaux*, *55*, 22–27.

Krausa, K., Hager, F. A., Kiatoko, N., & Kirchner, W. H. (2017). Vibrational signals of African stingless bees. *Insectes Sociaux*, *64*, 415–424.

Krausa, K., Hager, F. A., & Kirchner, W. H. (2017). The effect of food profitability on foraging behaviors and vibrational signals in the African stingless bee *Plebeina hildebrandti*. *Insectes Sociaux*, *64*, 567–578.

Kwapong, P., Aidoo, K., Combey, R., & Karikari, A. (2010). *Stingless Bees: Importance, management and utilisation*.

Louveaux, J., Maurizio, A., & Vorwohl, G. (1978). Methods of Melissopalynology. *Bee World*, *59*(4), 139–157.

Macharia, J. K., Raina, S. K., & Muli, E. M. (2007). *Stingless beekeeping: an incentive for rain forest conservation in Kenya*. 5.

Maitima, J. M., Mugatha, S. M., Reid, R. S., Gachimbi, L. N., Majule, A., Lyaruu, H., Pomery, D., Mathai, S., & Mugisha, S. (2009). The linkages between land use change, land degradation and biodiversity across East Africa. *African Journal of Environmental Science and Technology*, *3*, Article 10.

Meléndez Ramírez, V., Ayala, R., & Delfín González, H. (2018). Crop Pollination by Stingless Bees. In P. Vit, S. R. M. Pedro, & D. W. Roubik (Eds.), *Pot-Pollen in Stingless Bee Melittology* (pp. 139–153). Springer International Publishing.

Michener, C. D. (1974). *The Social Behavior of the Bees: A Comparative Study*. Harvard University Press.

Misana, S. B., Sokoni, C., & Mbonile, M. J. (2012). Land-use/cover changes and their drivers on the slopes of Mount Kilimanjaro, Tanzania. *Journal of Geography and Regional Planning*, *5*(6).

Morse, R. A. (1994). The new complete guide to beekeeping. *The New Complete Guide to Beekeeping.*

Moshi District Council. (2016, December). *Moshi District Council—Strategic Plan*. https://moshidc.go.tz/storage/app/uploads/public/58d/253/b01/58d253b01dc5610244 2074.pdf

Mpuya, P. M. (2009). Beekeeping potential for economic development and need for environmental conservation in Tanzania. *Liseki, S (Ed.) Beekeeping Environmental Conservation Newsletter - TAWIRI*, *3*, 2–4.

Murillo, R. M. (1984). Uso y manejo actual de las colonias de *Melipona beecheii* (Apidae, Meliponinae) en el Estado de Tabasco, México. *Biotíca*, *9*, 422–428.

Mustafa, M. Z., Yaacob, N. S., & Sulaiman, S. A. (2018). Reinventing the Honey Industry: Opportunities of the Stingless Bee. *The Malaysian Journal of Medical Sciences : MJMS*, *25*, 1–5.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*, 853–858.

Ndungu, N. N., Kiatoko, N., Ciosi, M., Salifu, D., Nyansera, D., Masiga, D., & Raina, S. K. (2017). Identification of stingless bees (Hymenoptera: Apidae) in Kenya using morphometrics and DNA barcoding. *Journal of Apicultural Research*, *56*, 341–353.

Nicholson, S. E. (2000). The nature of rainfall variability over Africa on time scales of decades to millenia. *Global and Planetary Change*, *26*(1), 137–158.

Njau, M. A., Mturi, F. A., & Mpuya, P. M. (2010). Options for stingless honey-beekeeping around Udzungwa Mountains National Park, Tanzania, and implications for biodiversity management. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *6*, 89–95.

Nkoba, K., Raina, S. K., & Muli, E. (2012). *Species richness and nest dispersion of some tropical meliponine bees (Apidae: Meliponinae) in six habitat types in the Kakamega forest, western Kenya*. 9.

Nogueira-Neto, P. (1954). Notas bionômicas sobre meliponíneos: III–Sobre a enxameagem. *Arquivos Do Museu Nacional*, 419–451.

Nordin, A., Sainik, N. Q. A. V., Chowdhury, S. R., Saim, A. B., & Idrus, R. B. H. (2018). Physicochemical properties of stingless bee honey from around the globe: A comprehensive review. *Journal of Food Composition and Analysis*, *73*, 91–102.

Nunes, T. M., Mateus, S., Favaris, A. P., Amaral, M. F. Z. J., von Zuben, L. G., Clososki, G. C., Bento, J. M. S., Oldroyd, B. P., Silva, R., Zucchi, R., Silva, D. B., & Lopes, N. P. (2014). Queen signals in a stingless bee: Suppression of worker ovary activation and spatial distribution of active compounds. *Scientific Reports*, *4*, 7449.

Paavola, J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. *Environmental Science & Policy*, *11*, 642–654.

PalDat. (n.d.). Retrieved October 20, 2021, from https://www.paldat.org/

Pauly, A., & Vereecken, N. J. (2013). *Meliponinae d'Afrique*. Atlas Hymenoptera. http://www.atlashymenoptera.net/page.aspx?id=121

Pereboom, J. J. M., & Biesmeijer, J. C. (2003). Thermal constraints for stingless bee foragers: The importance of body size and coloration. *Oecologia*, *137*, 42–50.

Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Aizen, M. A., Biesmeijer, J. C., Breeze, T. D., Dicks, L. V., Garibaldi, L. A., Hill, R., Settele, J., & Vanbergen, A. J. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, *540*, 220–229.

Potts, S. G., Vulliamy, B., Dafni, A., Ne'eman, G., & Willmer, P. (2003). Linking Bees and Flowers: How Do Floral Communities Structure Pollinator Communities? *Ecology*, *84*, 2628–2642.

R Core Team. (2020). *R: A language and environment for statistical computing*. https://www.r-project.org/

Ramalho, M., Giannini, T. C., Malagodi-Braga, K. S., & Imperatriz-Fonseca, V. L. (1994). Pollen Harvest by Stingless Bee Foragers (Hymenoptera, Apidae, Meliponinae). *Grana*, *33*, 239–244.

Ramalho, M., Kleinert-Giovannini, A., & Imperatriz-Fonseca, V. L. (1990). Important bee plants for stingless bees (*Melipona* and *Trigonini*) and Africanized honeybees (*Apis mellifera*) in neotropical habitats: A review. *Apidologie*, *21*, 469–488.

Ramírez-Arriaga, E., Pacheco-Palomo, K. G., Moguel-Ordoñez, Y. B., Zepeda García Moreno, R., & Godínez-García, L. M. (2018). Angiosperm Resources for Stingless Bees (Apidae, Meliponini): A Pot-Pollen Melittopalynological Study in the Gulf of Mexico. In P. Vit, S. R. M. Pedro, & D. W. Roubik (Eds.), *Pot-Pollen in Stingless Bee Melittology* (pp. 111–130). Springer International Publishing.

Roubik, D. W. (1989). *Ecology and Natural History of Tropical Bees*. Cambridge University Press.

Roubik, D. W. (2006). Stingless bee nesting biology. *Apidologie*, *37*, 124–143.

Sagwa, C. B. (2021). Bee populations, genetic diversity, conservation, marketing and contribution to rural households in Kenya: A review. *International Journal of Tropical Insect Science*.

Salatino, A., Regnier, L., Pereira, L., Luiza, M., & Salatino, F. (2019). *The emerging market of propolis of stingless bees in tropical countries*. 27–29.

Schüler, L., & Hemp, A. (2016). Atlas of pollen and spores and their parent taxa of Mt Kilimanjaro and tropical East Africa. *Quaternary International*, *425*, 301–386.

Sébastien, L. (2010). The Chagga people and environmental changes on Mount Kilimanjaro: Lessons to learn. *Climate and Development*, *2*, 364–377.

Sihag, R. C. (1995). Pollination, pollinators and pollination modes: Ecological and economic importance. *Pollination of Cultivated Plants in the Tropics (Roubik DW, Ed.). FAO Agricultural Services Bulletin*, 11–39.

Silva, C., N Radaeski, J., Victorino Nicolosi Arena, M., Bauermann, S., Veiga, A., Limão, A., Saraiva, A., Kleinert, A., Freitas, B., Costa, C., Maia-Silva, C., Poveda Coronel, C., Krug, C., Alvarado Ospino, D., Alarcón-Prado, D., Riaño, D., Gomes, F., Gruchowski Woitowicz, F. C., Santos, F., & Imperatriz-Fonseca, V. L. (2020). *Atlas of pollen and plants used by bees*.

Sinyangwe, J., Kimaro, D. N., Kajembe, G. C., & Mbeyale, G. E. (2010). *Stakeholders' views and perceptions on emerging conflicts with respect to apiculture in the western Usambara mountains, Tanzania*.

Slaa, E. J., Alejandro Sánchez Chaves, L., Katia Sampaio Malagodi-Braga, & Elisabeth Hofstede, F. (2006). Stingless bees in applied pollination: Practice and perspectives. *Apidologie*, *37*, 293–315.

Slaa, E., Sánchez, L., Sandí, M., & Salazar, W. (2000). A scientific note on the use of stingless bees for commercial pollination in enclosures. *Apidologie*, *31*, 141–142.

Smith, F. G. (1958). Beekeeping Observations in Tanganyika 1949–1957. *Bee World*, *39*, 29–36.

Soares, T., Jesus, O., Souza, E., Rossi, M., & Oliveira, E. (2017). Comparative pollen morphological analysis in the subgenera *Passiflora and Decaloba*. *Anais Da Academia Brasileira de Ciências*, *90*.

Soini, E. (2005a). Changing livelihoods on the slopes of Mt. Kilimanjaro, Tanzania: Challenges and opportunities in the Chagga homegarden system. *Agroforestry Systems*, *64*, 157–167.

Soini, E. (2005b). Land use change patterns and livelihood dynamics on the slopes of Mt. Kilimanjaro, Tanzania. *Agricultural Systems*, *85*, 306–323.

Tropek, R., Padysakova, E., & Janecek, S. (2018). Floral Resources Partitioning by Two Co-occurring Eusocial Bees in an Afromontane Landscape. *Sociobiology*, *65*, 527–530.

Tutuba, N. B., & Vanhaverbeke, W. (2018). Beekeeping in Tanzania: Why is beekeeping not commercially viable in Mvomero? *Afrika Focus*, *31*, Article 1.

United Nations. (2015). *THE 17 GOALS | Sustainable Development*. https://sdgs.un.org/goals

Van Gysel, V. (2017). *Bijvriendelijk bermbeheer,*. KU Leuven Faculteit Industriële Ingenieurswetenschappen.

van Huis, A. (2020). Cultural aspects of ants, bees and wasps, and their products in sub-Saharan Africa. *Int J Trop Insect Sci*, 13.

Viswanath, S., & Lubina, P. A. (2017). Traditional Agroforestry Systems. In J. C. Dagar & V. P. Tewari (Eds.), *Agroforestry: Anecdotal to Modern Science* (pp. 91–119). Springer.

Vit, P., Pedro, S. R. M., & Roubik, D. (2013). *Pot-Honey: A legacy of stingless bees*. Springer Science & Business Media.

Von Der Ohe, W., Persano Oddo, L., Piana, M. L., Morlot, M., & Martin, P. (2004). Harmonized methods of melissopalynology. *Apidologie*, *35*(Suppl. 1), S18–S25.

von Hellermann, P. (2016). Tree symbolism and conservation in the South Pare Mountains, Tanzania. *Conservation and Society*, *14*(4), 368.

Wagner, K., Meilby, H., & Cross, P. (2019). Sticky business—Why do beekeepers keep bees and what makes them successful in Tanzania? *Journal of Rural Studies*, *66*, 52–66.

Wilson, R. S., Keller, A., Shapcott, A., Leonhardt, S. D., Sickel, W., Hardwick, J. L., Heard, T. A., Kaluza, B. F., & Wallace, H. M. (2021). Many small rather than few large sources identified in long-term bee pollen diets in agroecosystems. *Agriculture Ecosystems & Environment*, *310*, 107296.

Appendix

Appendix A SUMMARY OF STINGLESS BEE SPECIES OF TANZANIA

Table A-1: Summary of stingless bee species of Tanzania (Hamisi, 2016)

S/N	Genus	Species	References
1	*Axestotrigona*	*A. erythra* Schletterer	(Eardley, 2004; Mpuya, 2009)
2	*Cleptotrigona*	*C. cubicerps* Friese	(Eardley, 2004; Eardley et al., 2010)
3	*Dactylurina*	*D. schmidti* Stadelmann	(Eardley, 2004; Pauly & Vereecken, 2013)
4	*Hypotrigona*	*H. Araujo* Michener	(Eardley, 2004)
		H. gribodoi Magretti	(Eardley, 2004)
		H. ruspolii Magretti	(Eardley, 2004; Pauly & Vereecken, 2013)
5	*Liotrigona*	*L. bottegoi* Magretti	(Eardley, 2004; Pauly & Vereecken, 2013)
6	*Meliponula*	*M. ferruginea* Lepeletier	(Eardley, 2004; Pauly & Vereecken, 2013)
		M. oguensis Vichal	(Eardley, 2004; Pauly & Vereecken, 2013)
		M. landiliana Friese	(Eardley, 2004; Pauly & Vereecken, 2013)
		M. becearii Gribodo	(Eardley, 2004; Pauly & Vereecken, 2013)
		M. bocandei Spinola	(Mpuya, 2009; Pauly & Vereecken, 2013)
		M. junodi Cockerell	(Mpuya, 2009)
7	*Plebeina*	*P. armata* Magretti	(Pauly & Vereecken, 2013)
		P. hildebrandti Friese	(Eardley, 2004; Pauly & Vereecken, 2013)
8	*Trigona*	*T. denoiti* Vichal	(Mpuya, 2009; Pauly & Vereecken, 2013)
		T. spinipes Fabr	(Mpuya, 2009)

Appendix B RESULTS FROM POLLEN ANALYSIS

a. PLANT FAMILIES IDENTIFIED BY THEIR POLLEN IN SAMPLE FROM KIBOSHO WARD

Table A-2: Plant families identified by their pollen in sample from Kibosho ward

Kibosho 1
Predominant pollen (>45% of pollen counted)
/
Secondary pollen (16-45% of pollen counted)
Cannabaceae
Poaceae
Important minor pollen (3-15% of pollen counted)
Asteraceae
Brassicaceae
Bignoniaceae
Minor pollen (<3% of pollen counted)
Acanthaceae
Euphorbiaceae
Myrtaceae
Proteaceae
Rosaceae

b. PLANT FAMILIES IDENTIFIED BY THEIR POLLEN IN SAMPLES FROM MBOKOMU WARD

Table A-3: Plant families identified by their pollen in sample from Mbokomu ward

Mbokomu 1	*Mbokomu 2*	*Mbokomu 3*	*Mbokomu 4*
Predominant pollen (>45% of pollen counted)			
Poaceae	Cannabaceae	Asteraceae	/
Secondary pollen (16-45% of pollen counted)			
Cannabaceae	Asteraceae	/	Cannabaceae Poaceae
Important minor pollen (3-15% of pollen counted)			
Boraginaceae Euphorbiaceae Verbenaceae	Acanthaceae Fabaceae Myrtaceae	Brassicaceae Fabaceae Lauraceae Moraceae Myrtaceae Poaceae Oleaceae Poaceae	Moraceae Myrtaceae Rosaceae Solanaceae
Minor pollen (<3% of pollen counted)			
Asteraceae Lauraceae	Aquifoliaceae Brassicaceae Oleaceae Phyllanthaceae Poaceae Verbenaceae	Bignoniaceae Melastomataceae	Aquifoliaceae Asteraceae Fabaceae Lauraceae Oleaceae

c. Plant families identified by their pollen in samples from Kilema-Marangu transect

Table A-4: Plant families identified by their pollen in sample from Kilema-Marangu transect

Kilema-Marangu 1	*Kilema-Marangu 2*	*Kilema-Marangu 3*
Predominant pollen (>45% of pollen counted)		
Asteraceae	/	/
Secondary pollen (16-45% of pollen counted)		
/	Asteraceae Myrtaceae Poaceae	Asteraceae Oleaceae
Important minor pollen (3-15% of pollen counted)		
Lauraceae Myrtaceae Poaceae Rosaceae Solanaceae	Phyllanthaceae Solanaceae	Moraceae Poaceae
Minor pollen (<3% of pollen counted)		
Brassicaceae Cannabaceae Fabaceae Loranthaceae Oleaceae Verbenaceae	Burseraceae Fabaceae Lauraceae Moraceae	Proteaceae Rosaceae

d. PLANT FAMILIES IDENTIFIED BY THEIR POLLEN IN SAMPLES FROM THE SOUTH PARE MOUNTAINS

Table A-5: Plant families identified by their pollen in sample from the South Pare mountains

South Pare 1	*South Pare 2*
Predominant pollen (>45% of pollen counted)	
/	/
Secondary pollen (16-45% of pollen counted)	
Brassicaceae	Brassicaceae
Moraceae	Burseraceae
	Ebenaceae
Important minor pollen (3-15% of pollen counted)	
Amaranthaceae	Asteraceae
Asteraceae	Cannabaceae
Fabaceae	Lauraceae
Lauraceae	Myrtaceae
Minor pollen (<3% of pollen counted)	
Cannabaceae	Amaranthaceae
Bignoniaceae	Aquifoliaceae
Myrtaceae	Loranthaceae
Rosaceae	Malvaceae
	Phyllanthaceae

Appendix C KIHAMBA PLANTS MENTIONED BY SMALLHOLDER FARMERS AS MAJOR FORAGE SOURCES FOR STINGLESS BEES (FLORAL CALENDAR)

a. MT. KILIMANJARO

Table A-6: Homegarden plants which were reported to serve as forage sources for stingless bees on Mt. Kilimanjaro (n=18)

Scientific name of plant	Plant family	Times mentioned by smallholder farmers	Flowering time
Grevillea robusta	Proteaceae	11	Year-round
Persea americana	Lauraceae	10	March-April
Coffea spp.	Rubiaceae	6	July-December, December-January
Musa spp.	Musaceae	6	Year-round
Brassica olearacea	Brassicaceae	5	January-September
Albizia schimperiana	Fabaceae	4	March-April, September-October
Callistemon spp.	Myrtaceae	3	January-March, June-September
Brugmansia suaveolens	Solanaceae	2	Year-round
Zea mays	Poaceae	2	April-May
Carica papaya	Caricaceae	1	Year-round
Psidium guavaja	Myrtaceae	1	Year-round
Passiflora edulis	Passifloraceae	1	Year-round
Vigna unguiculata	Fabaceae	1	April-May, November-December
Hibiscus spp.	Malvaceae	1	Year-round with peak October-May
Eucalyptus spp.	Myrtaceae	1	Year-round
Solanum aethiopicum	Solanaceae	1	Year-round
Persicaria capitata	Polygonaceae	1	Year-round
Achillea distans	Asteraceae	1	Year-round with peak January-March
Lantana camara	Verbenaceae	1	Year-round with peak March-April
Calliandra spp.	Fabaceae	1	Year-round

b. South Pare Mountains

Table A-7: Homegarden plants which were reported to serve as forage sources for stingless bees in the South Pare mountains (n=4)

Scientific name of plant	Plant family	Times mentioned by smallholder farmers	Flowering time
Persea americana	Lauraceae	3	March-April
Zea mays	Poaceae	3	April-May
Musa spp.	Musaceae	3	Year-round
Mangifera indica	Anacardiaceae	2	March-April, September-October
Annona senegalensis	Annonaceae	2	April-June
Solanum aethiopicum	Solanaceae	2	Year-round
Cucurbita spp.	Cucurbitaceae	1	Year-round
Ipomoea batatas	Convolvulaceae	1	Year-round
Senna spectabilis	Fabaceae	1	Year-round
Psidium guavaja	Myrtaceae	1	Year-round
Albizia spp.	Fabaceae	1	March-April, September-October
Manihot esculenta	Euphorbiaceae	1	May-October
Coffea spp.	Rubiaceae	1	July-December, December-January
Telfairia pedata	Cucurbitaceae	1	Year-round

Appendix D SURVEY USED DURING FIELD WORK

A) GENERAL INFORMATION ON HOUSEHOLD

Date:

District:…………………………………………

Ward:…………………………………………… Village:…………………………………………

Altitude: ………………………………………… GPS: X-coordinate:

Y-coordinate:

1. Who is the main beekeeper in the household?
   - Father
   - Mother
   - Youth
   - Grandfather
   - Grandmother
   - Others: …..

2. Do other members of the household help with tasks related to beekeeping?
   - Father
   - Mother
   - Youth
   - Grandfather
   - Grandmother
   - No help

3. Which tasks do they help with?
   - Inspecting colonies
   - Harvesting honey
   - Protecting the colonies (from predators, pests, …)
   - Others: …..

4. The educational level of people in your household:
   - Father:
   - Mother:
   - Children:
   - (Grandfather):
   - (Grandmother):

5. Primary occupation of the household:
   - Crop cultivation
   - Livestock
   - Mixed farming
   - Non-related to agriculture, specify: ………..

B) INFORMATION ON HIVES

Table A-8: Hive information asked during survey

Number of hives	Type of hive	Measurements	Annual production	Occupancy (Yes/No)	Source	Age of colony	(Bee species)	Placement	Direction of entrance	Height from the ground
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

C) General information on stingless beekeeping

1. For how long have you been practicing stingless beekeeping?

2. How many fellow beekeepers do you know? (excluding beekeepers they've sold colonies to)

3. Why did you take on stingless beekeeping?
    - Family tradition
    - Pollination benefits
    - Revenue from beekeeping products
    - Others: ……..
4. Is stingless beekeeping practiced by other members of your family?
    - Yes
    - No
5. How did you learn to keep bees?
    - Alone
    - From family
    - From a friend
    - From a government issued program
    - Other: …..
6. Have you taken a course on stingless beekeeping?
    - Yes
    - No
7. Why did you choose stingless beekeeping over stinging beekeeping?
    - Hives can be closer to house
    - Higher price for honey
    - Family tradition
    - No need for special equipment
    - Found a wild nest
    - Others: ……
8. What do you think is the largest constraint for stingless beekeeping in the area?
    - Lack of knowledge
    - Lack of government support
    - Lack of equipment
    - Others: ……..
9. Why do you think that stingless beekeeping is not as popular as stinging beekeeping?
    - Less production
    - Lack of knowledge about the existence
    - Others: ……….
10. How far from the entrance of the house are the hives?
    - 0-5m
    - 5-15m
    - 15-30m
    - More than 30m
11. Do you use pesticides or herbicides in your homegarden?
    - Pesticides
    - Herbicides
    - Both

- None

12. Do you have knowledge of the application of pesticides or herbicides around your homegarden?
    - No knowledge
    - Pesticides
    - Herbicides
    - None applied
    - Both applied
13. What do you think is the largest threat to stingless beekeeping?
    - Use of pesticides
    - Lack of food (hunger gap)
    - Predators
    - Pests
    - Others: ………..

D) Beekeeping management skills

14. How many colonies have you successfully multiplied over the last year?

15. How many colonies have you lost over the last year?

16. How do you harvest the honey?
    - Fire
    - Splitting and scooping
    - Poking open the storage and flipping the box
    - Extraction by syringe
    - Extraction by pump
    - Others: …….
17. Do you take active measures to control the swarming behaviour of the stingless bees?
    - Limiting food
    - No measures taken
    - Others: …..
18. Do you selectively breed your bees based on valuable characteristics?
    - Yes
    - No
19. With which frequency do you inspect the colonies?
    - Daily
    - Every two days
    - Weekly
    - Every two weeks
    - Monthly
    - Yearly
    - Never
20. How much time do you spend on beekeeping related activities on average each week?

E) Threats to the bee colony

21. What pests threaten the colony, and when do they occur most frequently?

Table A-9: Question about threats to the bee colony in survey

Name of pest	Countermeasure	Period of high risk

F) Sale of hive products

22. How do you store the honey?
    - Pasteurization
    - Refrigeration
    - No special measures
    - Others: ……

23. What percentage of your income is generated by the sale of farming products?

G) Foraging

24. Do you provide supplementary water for the bees?
    - Yes → When?
    - No
25. How would you describe the foraging pattern of stingless bees?
    - Flying directly towards plant
    - Making several stops before going to plant
    - Going to plant and returning to recruit other foragers
    - Others: ………
26. Do you take active measures to protect plants which serve as forage for the bees?
    - Yes
    - No
27. Do the bees also forage outside the homegarden?
    - Yes → When and where?
    - No
28. What do you think is a problem that needs to be investigated in stingless beekeeping?

29. Which plants do you think are important as forage for stingless bees and do you know for which resource they are important?

Table A-10: Important plants for stingless bees: survey question

Local name of plant	Scientific name of plant	Time when bees collect forage from this plant	(Time of harvest)	Importance as nectar source	Importance as pollen source	Other function for bees

H) POLLINATION

30. Have you seen a difference in yield after you have started practicing stingless beekeeping? If so, with which plants?
    - No difference
    - Difference, namely the following plants

Table A-11: Plants pollinated by stingless bees: survey question

Local name of plant	Scientific name of plant

31. Which crops do you cultivate?

Table A-12: Characterisation of homegarden in survey

Local name of plant	Scientific name	Relative abundance as percentage of total crops

Appendix E SCREENSHOTS FROM THE SMARTPHONE APPLICATION

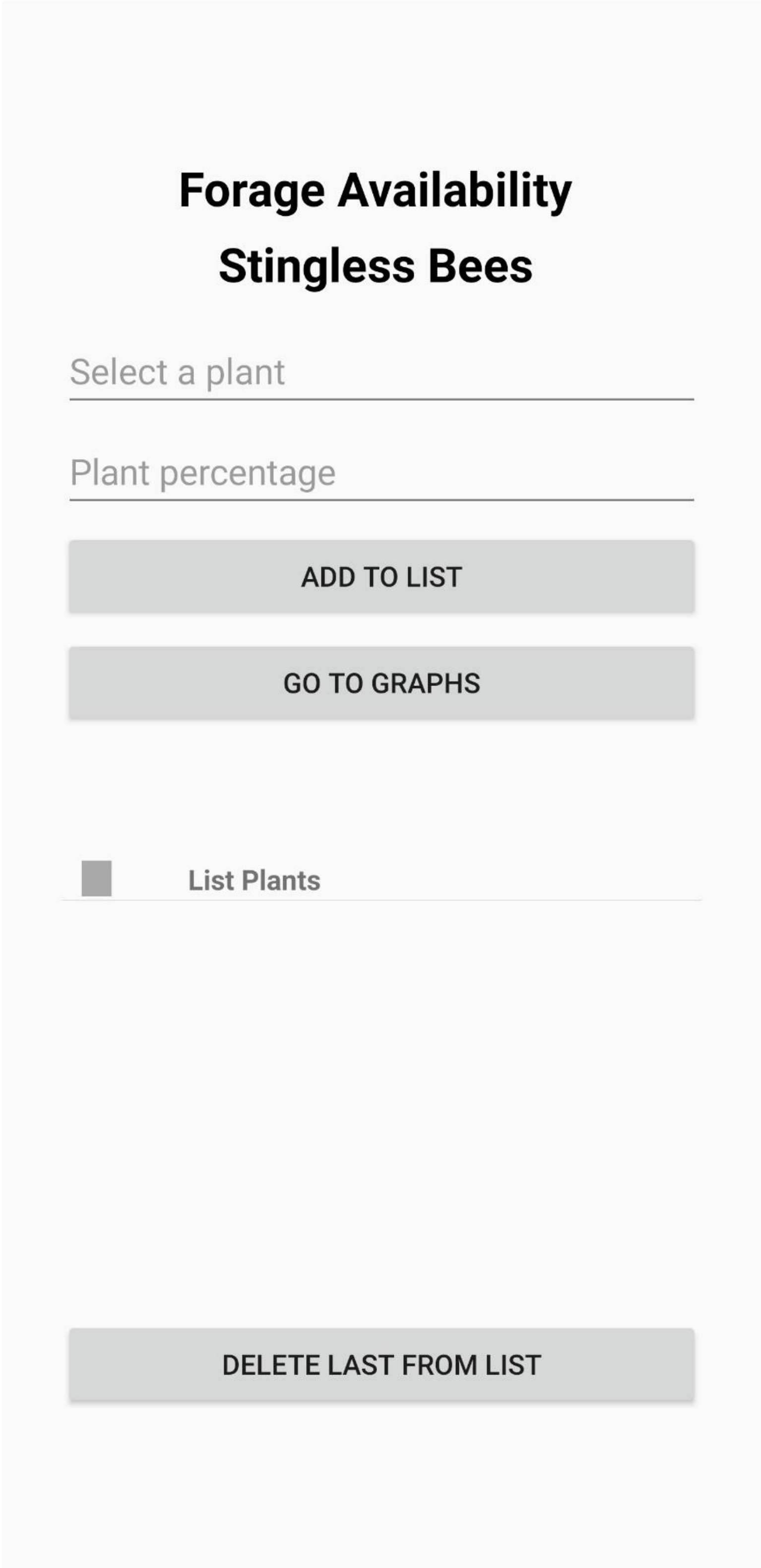

Figure A.1: Starting screen of application

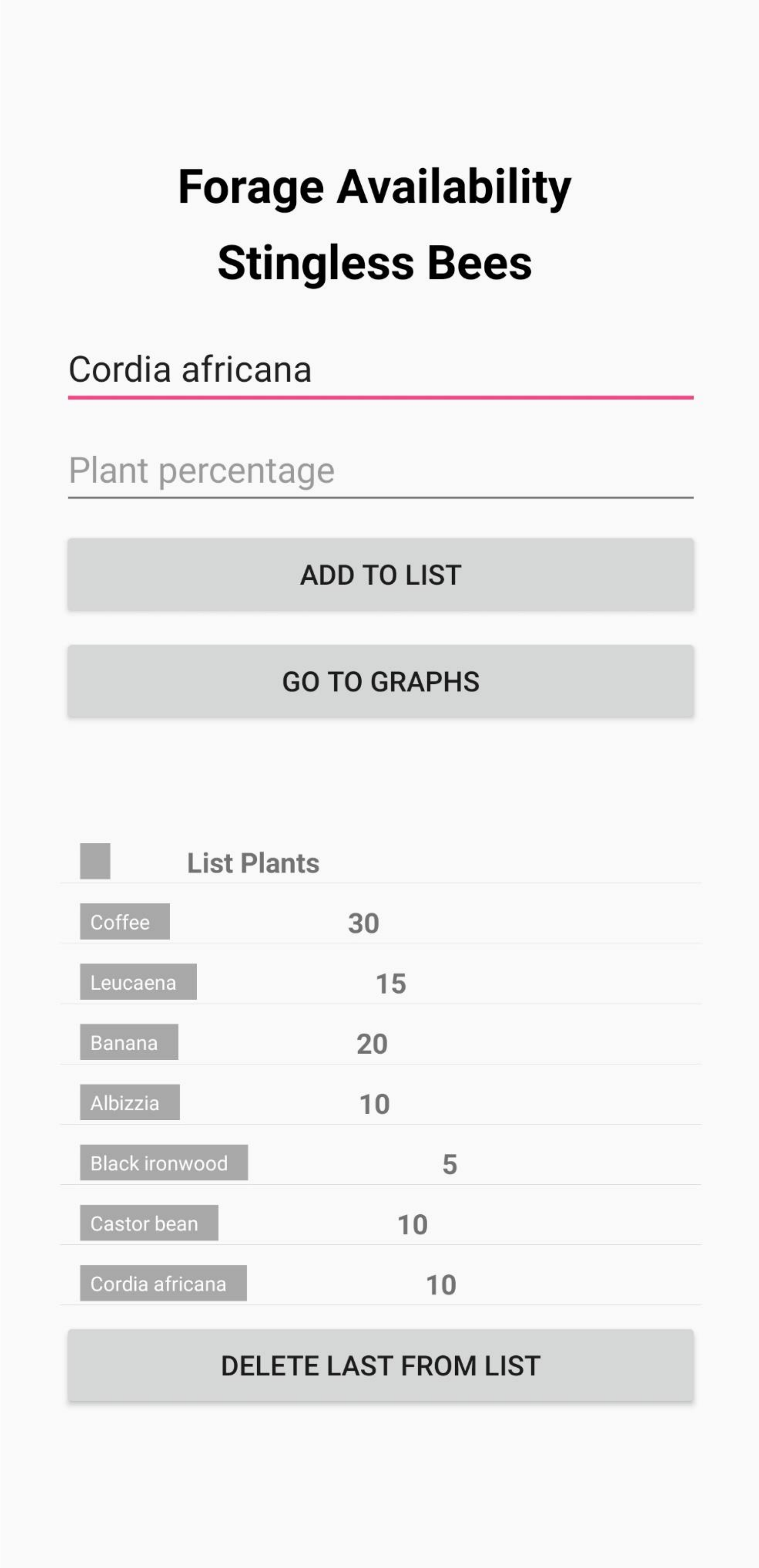

Figure A.2: Screen after entry of plants which are present in homegarden

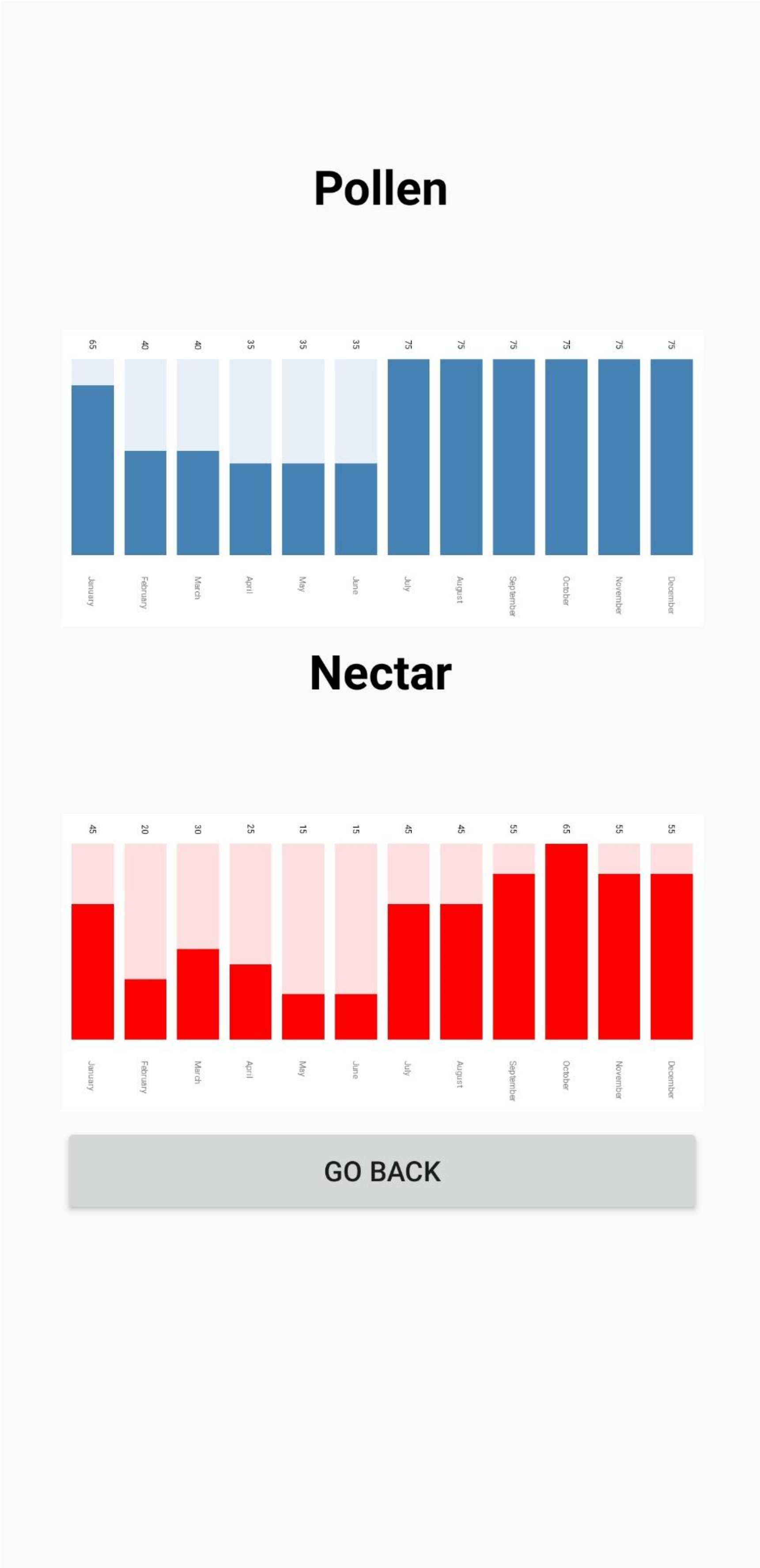

Figure A.3: Graphical representation of forage availability

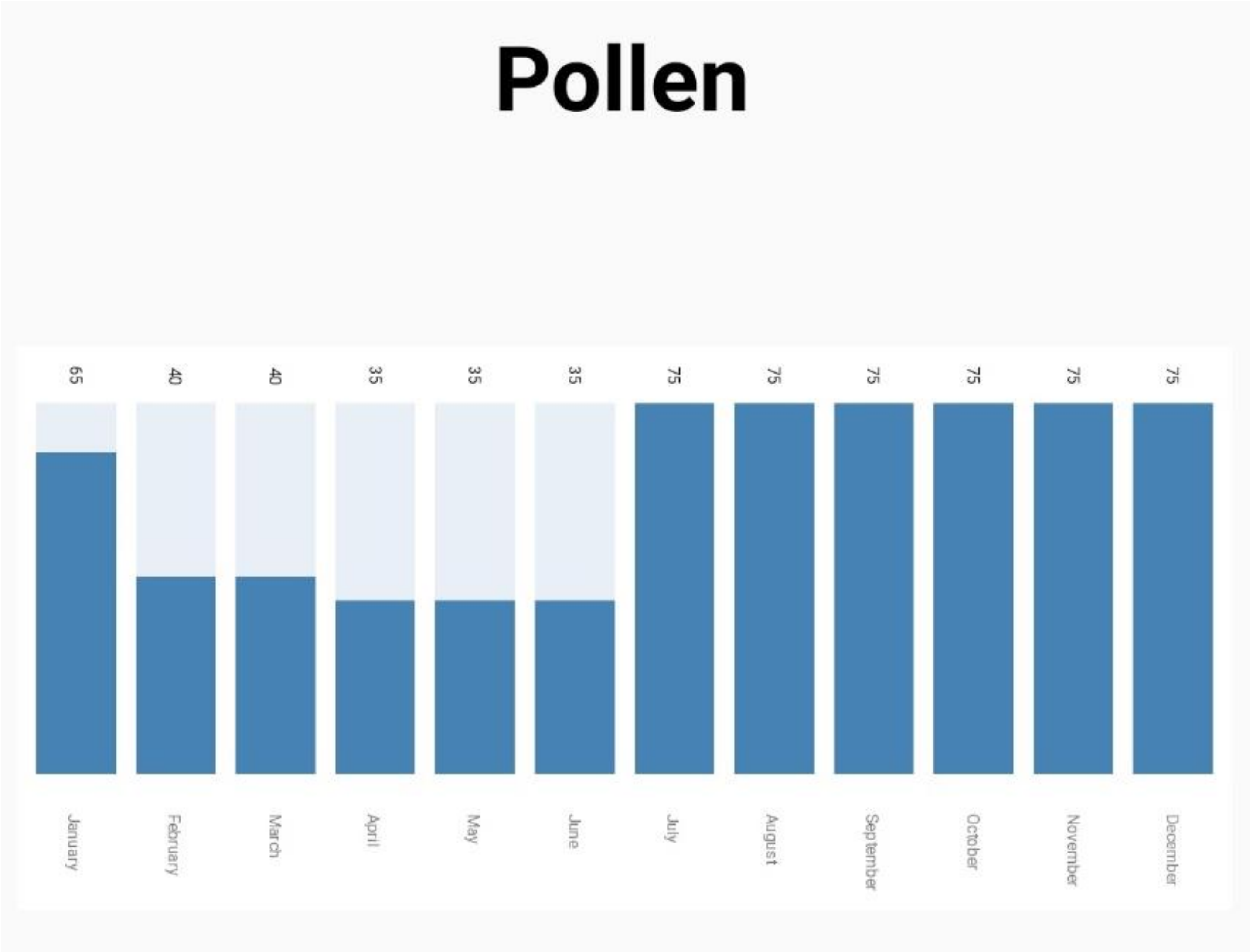

Figure A.4: Larger example of pollen availability in homegarden

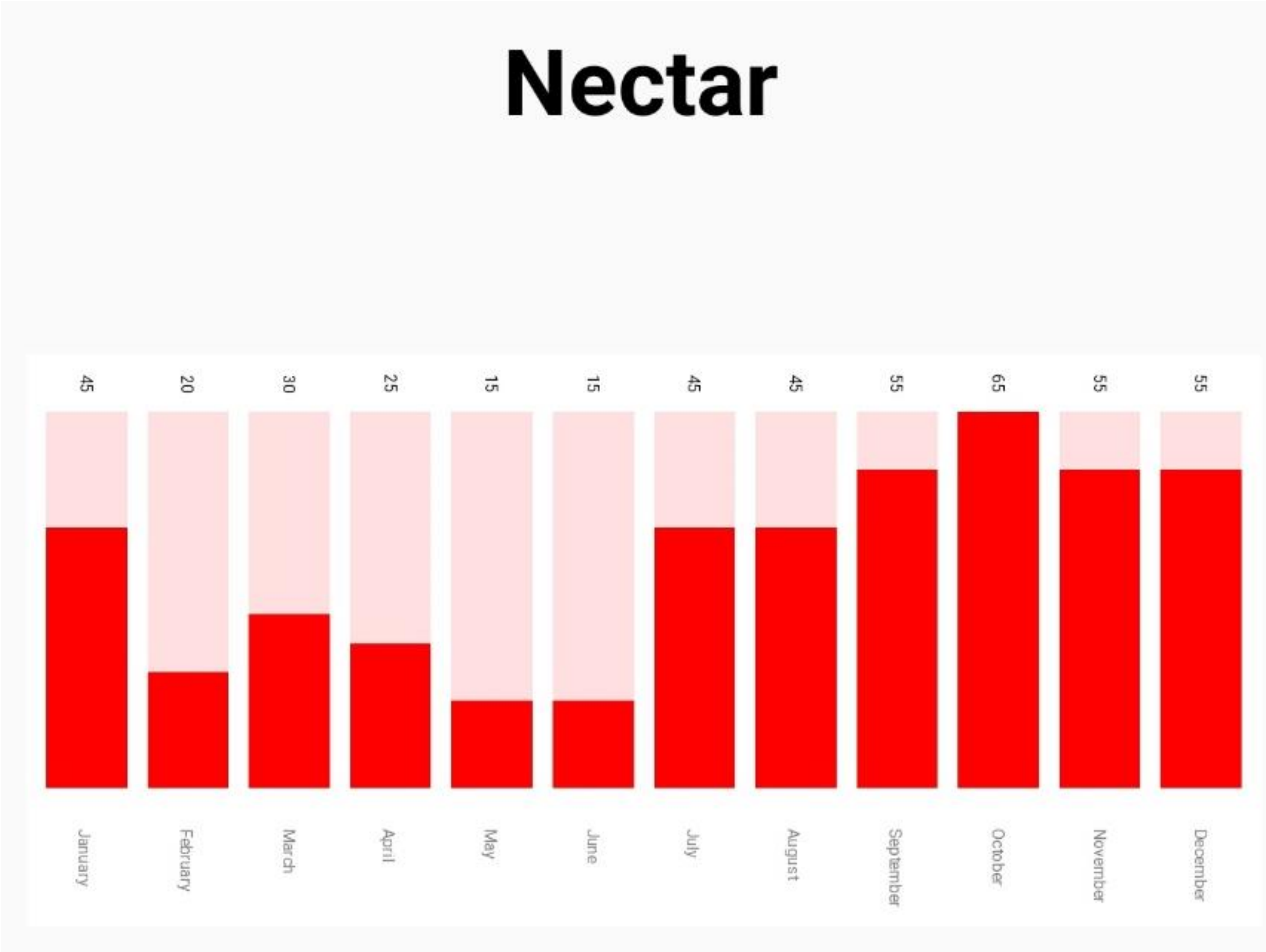

Figure A.5: Larger example of nectar availability in homegarden

FACULTEIT INDUSTRIËLE INGENIEURSWETENSCHAPPEN
CAMPUS GEEL
Kleinhoefstraat 4
2440 GEEL, België
tel. + 32 14 72 13 00
iiw.geel@kuleuven.be
www.iiw.kuleuven.be