

**FACTORS AFFECTING THE PERFORMANCE OF AFRICAN
HONEY BEE COLONIES IN UGANDA**

By

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DECLARATION

I Otim Agnes Sarah, hereby declare that the research in this thesis is a result of my own work and that all sources or materials used for this thesis have been acknowledged. This thesis is submitted in fulfillment of the requirements for the award of a Doctor of Philosophy Degree in Zoology of Gulu University, in Uganda, to be made available to the University's Library under the rules of Gulu University Library. I confidently declare that this thesis has not been submitted to any institution for the award of any academic degree, diploma or certificate.

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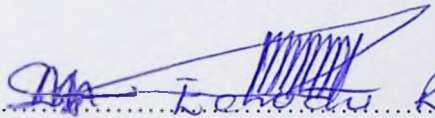
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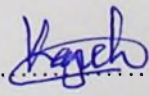
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DEDICATION

I dedicate this work to my Lord Jesus who has enabled me to go through this study and to my husband Etochu Joseph, my Parents Clement and Mary Otim, sisters Sanyu, Manku, Nancy, Martha and brothers Musa, Joni, Deo and Anthony.

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ABBREVIATIONS, SYMBOLS AND ACRONYMS

ABPV	Acute bee paralysis virus,
AEZs	Agro-ecological zones
ANOVA	Analysis of variance
BQCV	Black Queen Cell Virus
CBPV	Chronic Bee Paralysis Virus,
DNA	Deoxyribonucleic Acid
DRC	Democratic Republic of Congo
DWV	Deformed wing virus
EFSA	European Food Safety Authority
EU	European Union
FAO	Food and Agriculture Organisation
IABP	Israeli acute bee paralysis
IAPV	Israeli acute paralysis Virus, IAPV
IRGS	Institute of Research and Graduate Studies
KBV	Kashmir Bee Virus;
KP	Kyoga Plains
KTB	Kenyan top bar hive
LSV	Lake Sinai virus
LVC	Lake Victoria Crescent
M.A.S.L	Meters above Sea Level
MN	Mid North
MT	Metric tones
NGOs	Non-Government Organisations
PCR	Polymerase Chain Reaction
RNA	Ribonucleic Acid
RT-PCR	Reverse Transcriptase - Polymerase Chain Reaction
SBV	Sacbrood virus
SPSS	Statistical Package for social sciences
TUNADO	The Uganda National Apiculture Development Organisation

VDV-1	<i>Varroa destructor</i> Virus-1
WH	Western highlands

ABSTRACT

Uganda's annual honey yield is lower than the expected production potential of 500,000 tones basing on the country's vegetation type. The aim of this study was to establish the factors that affect the performance of African honey bee colonies in honey production. It was conducted between May 2014 and May 2017 in four agro-ecological zones of Uganda where beekeeping is practiced viz- the Western highlands, Lake Victoria Crescent, Kyoga plains and North East savannah represented by Kabarole, Nakasongola, Tororo, and Lira, Kole districts respectively. Analyses of questionnaires administered to beekeepers on the socio-economic factors showed: high honey production observed among beekeepers ranking honey production as first position among their income generating activities, among beekeepers with only traditional hives compared to those with modern bee hives and those with available markets. Honey production was also ranked high in Kabarole and lowest in Tororo district. The production of honey did not increase with increasing number of colonized hives kept per farmer and neither did beekeeping trainings. Findings from hive inspections for honey bee pests showed: co-infestations with 2-4 different pest species in a single honey bee colony and the presence of the death head hawk moth, *Acherontia atropos* and *Oplostomus haroldi* in Lira and Nakasongola Districts, and a negative mean difference in honey production between the start and after 8 months that was attributed to co-infestations of pests. RT-PCR analyses detected five bee viruses BQCV, ABPV, SBV, CBPV and DWV in adult honey bee samples and also co-infections with 2-4 different bee virus species in a single honey bee colony. When the colonies were classified strong and weak, pathogen analyses revealed that the proportion of infected colonies with CBPV were less in strong than in weak infected colonies; implying its presence reduces bee numbers in African honey bee colonies. Analyses of bee forage species revealed that the production of honey per hive is not affected by the agro-ecological zone; instead it was influenced by the apiary location. This implies that bee forage species at the apiary location and other contributory factors at the site; pests and diseases affect honey production.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Honey bees *Apis mellifera* are beneficial insects from which many people have derived their livelihoods. The diet of honey bees consists of protein rich pollen and sugar rich nectar collected separately or synchronously from flowers by foraging worker bees; the nectar is converted into honey and pollen stored as bee bread (Nicolson, 2011; Anderson et al., 2014). While collecting nectar and pollen, bees deposit pollen from anthers to the stigma resulting in pollination and increased fruit set (Vidal et al., 2010). Globally 30% of the food crops and 90% of wild plants are dependent on honey bees for pollination (Chavaria, 1999). The value of honey bees in pollination services was estimated worldwide at €153 billion (Gallai et al., 2009). Besides pollination benefits valuable bee products namely; honey, bees wax, propolis, pollen, bee venom and royal jelly (Mutsaers et al., 2005). Honey is the major bee product traded worldwide. The total world honey production is estimated at 1,500,000 metric tons while Africa's honey production is at 169,306 tones (FAOSTAT, 2013).

1.2 Status of beekeeping in Uganda

Apiculture is a significant agricultural activity in Uganda, where bees are kept for honey and other bee products as sources of food and income (TUNADO 2003). The beekeeping enterprise in Uganda is cost effective than any other income generating activity. There is no need to purchase bee feeds as bees feed on nectar and pollen from available sources of existing natural bee plants. The beekeeping methods used range from traditional to modern; the traditional/fixed comb bee hives used are of various types depending on the location with locally available materials used for hive construction ranging from bamboo, palm tree logs, twigs and sticks (Kugonza & Nabakabya, 2008). Two types of modern hives made from timber are in use: Kenya Top bar hive (KTB) and the Langstroth hive. MAAIF/UBOS (2010) reported 750,000 hives in Uganda with 65.5% of them colonized, while 87.3% of the total hives are traditional hives the rest are KTB and Langstroth hives. There are over 120,000 beekeepers in Uganda organized around hon-

ey producer groups; some apiaries are group owned and others are owned by individuals. With the diversity of vegetation, indigenous knowledge and skills in bee keeping, Uganda has the capacity to produce 500,000 tons of honey per year (MAAIF/UBOS, 2010; Uepb, 2005).

1.3 Statement of the research problem

The beekeeping sector in Uganda is faced with the challenge of low honey production despite her rich flora and ecological conditions; the annual production is just 10% of the expected production potential. According to (faostat.org 2013), Uganda's annual honey production was at 712 tones. Most of the honeys sold in Uganda's super markets are imported (Kugonza & Nabakabya 2008). Honey continues to flow into the country from South Sudan and Democratic Republic of Congo (Jackson, 2004). Uganda is also one of the African countries exporting honey to the EU market but unable to meet the quantities required by the international market. A situation analysis of the beekeeping industry in Southern African countries (Total Transformation Agribusiness LTD, n.d.) reports limited honey production with all countries involved heavily depending on honey imports except Zambia, while South Africa exports and also imports to meet the demands of natural honey.

Evaluations on productivity of hives in Uganda has been done by MAAIF/UBOS (2010) and Kilimo Trust (2012). MAAIF/UBOS (2010) reported an average production per colonized hive of 3.9Kg/hive a much lower productivity than that reported in Ethiopia by Haftom & Awet (2013) of modern hives (22.8 Kg/hive) and KTBH (17.8Kg/hive). Kilimo Trust (2012) in their findings show current productivities of the different hives varying according to hive type traditional, KTB, and Langstroth; 5 Kg/hive/season, 12 Kg/hive/season, 14 Kg/hive/season respectively, while their potential productivities are 15 Kg/hive/season, 26 Kg/hive/season, 60 Kg/hive/season respectively and the yield gaps of the three hives are 67%, 54%, and 77%, respectively.

Some honey bee pests, parasites, and pathogens devastating honey bee colonies in Europe, Asia and America are now present in Uganda. For example *Varroa* mites are reported by Kasangaki et al. (2016); pathogens known to be transmitted by *Varroa* mites the Black Queen Cell Virus BQCV, Acute Bee Paralysis Virus, ABPV and Deformed Wing Virus, DWV, are reported in Uganda by Kajobe et al. (2010) and Chemurot (2017). Honey bee pests are reported by (Kajobe

et al., 2016). There is little information available on the current virus status in the Mid North AEZ.

Ndyomugenyi et al. (2015) and Kalanzi et al. (2015) in their studies in Uganda, discuss the socio demographic characteristics of beekeepers. Kalanzi et al. (2015) reported two socioeconomic factors of beekeepers that positively influence adoption of modern bee hives; education level and training in beekeeping. There was no literature available on socioeconomic factors of beekeepers influencing honey production in Uganda.

Kajobe et al. (2009) reported eleven pests in Uganda's honey bees; small hive beetles, wax moth, small black and red ants, were the most important pests causing economic losses, while spiders, termites, birds, lizards, snakes and rats were less important pests. There was a suspicion of new pests emerging, changes in prevalence and some of these pests contributing to the low honey production.

Kajobe et al. (2010) found one honey bee virus, the Black queen cell virus (BQCV). When BQCV was detected by Kajobe et al. (2010), *Varroa* mites had not been reported in Uganda's bee colonies and serious consequences were expected with BQCV disease after the detection of *Varroa* mites in the districts with BQCV (Kajobe et al., 2010; Kasangaki et al., 2016). Chemurot (2017), screened for 11 honey bee viruses in Uganda's bee colonies and detected five; Deformed wing virus, DWV, BQCV, Acute bee paralysis virus, ABPV, Lake Sinai virus and Sacbrood virus, LSV. Chemurot (2017) found, the number of viruses correlated with *Varroa* mite prevalence and number of combs with honey.

Varroa mites are known to vector various bee viruses and caused colony losses (Shen et al., 2005, Chantawannakul et al., 2006). With the presence of *Varroa* mites in Uganda's bee colonies, there was an assumption of changes in prevalence and presence of other bee viruses vectored by *Varroa* mites that could be impacting on the country's honey bee colony size and honey production.

The honey value analysis by Kilimo Trust (2012) shows high honey production in West Nile region and western Uganda with least production in central Uganda. According to Abou-Shaara (2015) knowledge of the honey bee floral sources specific to a region is essential for high honey

production. Bee forage species in Uganda have been studied by Katende et al. (1995), Kajobe (2006) Kajobe et al. (2009) and Kangave (2015). Kangave (2015) in Uganda identified forty six bee forage plant species belonging to twenty plant families in nine different agro-ecological zones. Kajobe (2006) and Kajobe et al. (2009) gives a list of plants used by the bees in Bwindi Impenetrable forest, Western highlands and Eastern agro-ecological zones. These authors don't relate the dominant bee forage in the studied zones with honey production differences.

The knowledge gaps noticed in the literature surrounding the factors affecting the performance of honey bee colonies in honey production in Uganda are: i) socio-economic factors of beekeepers influencing honey production ii) new pests, their prevalence and their likely implication to honey production iii) new bee viruses and their impact on the country's honey bee colony size and honey production iv) available bee forage plants in the different agro-ecological zones.

This study investigated the above issues through questionnaires, screening colonies for bee viruses using PCR methods, hive inspections for pests and bee forage plants identified after observation of bees foraging on plants. The findings are then related to their likely implication to honey bee colony size and honey production

1.4 General objective

The general objective of this study was to determine factors contributing to the low levels of honey production and performance in Uganda.

1.4.1 Specific objectives

1. To determine the socio-economic factors of beekeepers influencing honey production
2. To identify the honey bee pests affecting the production of honey in Uganda
3. To identify the pathogens (bee viruses) affecting honey production
4. To determine key bee forages responsible for honey production in the different AEZs in Uganda.

1.4.2 Research questions

- a) Which socio-economic characteristics of beekeeping farmers affect honey production in Uganda?
- b) Which pests affect honey production in Uganda's honey bee colonies?
- c) Which pathogens affect honey production in Uganda's honey bee colonies?
- d) Which bee forages are responsible for honey production in the studied areas?

1.5 Justification of the study

Beekeeping is seen as one of the economic activities in which many Ugandans all over the country are involved and has a potential of widening the country's export base (Uepb, 2005). To this effect the country formed The National Apiculture Development Organisation (TUNADO) to re-organise the sector. There are over 120,000 beekeepers also deriving their livelihoods from beekeeping product sales. Besides hundreds of crops from which the whole population depends on benefit from pollination by the bees. Low production of honey directly affects the beekeepers and the country's export earnings. Anything affecting the colony size affects pollination of crops and honey production. The methods that were used to obtain the findings had previously been used in similar studies see chapter 3. Therefore this study was necessary to inform policy on the factors affecting the performance of bees for their action.

1.6 Significance of the study

The society that benefits from this study includes; the beekeepers, stake holders (MAAIF, Extension, NGO's, UEPB, UNBS) and researchers. This audience benefits from these findings in the following ways; the socio-economic factors associated with high honey production identified from this study are recommended to beekeepers for increased honey yield. The distribution of pests, parasites and pathogens informs policy, extension and stake holders on their management in Uganda's bee colonies. Knowledge of honey bee floral sources responsible for high honey production in the different agro-ecological zones is necessary as beekeepers can use this information to select locations for apiary sites and conserve plants that are important to the bees.

1.7 Thesis Structure

The structure adopted in this thesis is the most recent PhD guidelines for Gulu University, where it is recommended that some of the chapters be presented as per the objectives and published papers.

Chapter one is an introductory chapter that gives an overview of the problem of honey production, in Uganda and background information on beekeeping sector in Uganda, statement of research problem and justification of the study. Chapter one also gives the objectives of the study, research questions tested to achieve these objectives and format adapted in writing this PhD thesis.

Chapter two deals with literature review on the status of beekeeping sector in Uganda and sub-Saharan Africa. This chapter examines what other authors have done and the findings, observations and conclusions that have been made about beekeeping sector in Uganda and other areas.

Chapter three deals with general description of the study area as well as an explanation on the design and rationale of the sampling scheme, and the honey bee sampling procedure.

Chapter four describes the socio economic characteristics of beekeeping farmers that were examined to determine the factors influencing honey production; the education level of the beekeeper, age, rank of beekeeping in income generation, number of years spent in beekeeping practice, market availability, location or district of origin, record keeping of the beekeeping enterprise and number of trainings in honey production received by the beekeeper. Other aspects described include; the type of hives, total number, and number of colonized hives kept per farmer.

Chapter five discusses the pests and parasites affecting honey bees in Uganda that were explored in hive inspections. This chapter also gives the existing honey bee pests and parasite species, and their distribution. Other aspects that are investigated include change in number of infested colonies and whether the observed low honey production is linked to infested colonies.

Since *Varroa* mites were common in honey bee colonies and are known to vector bee viruses. Adult honey bees were screened for six common bee viruses using RT-PCR methods (ABPV,

BQCV, DWV, KBV, CBPV, and SBV). The detected viruses were individually compared with colony strength of infected colonies, these findings are described in chapter 6.

The bees convert the nectar collected from flowers to honey. Forages responsible for honey production in the different agro-ecological zones were studied by observation of bees foraging on flowers, this is discussed in Chapter 7. This chapter also discusses how the bee forage species cover contributes to the observed low production.

In chapter 8 the key results of this study are discussed including recommendations on the applicability of the findings.

CHAPTER TWO

LITERATURE REVIEW

2.1 Honey bee species

Honey bees are social insects that belong to order Hymenoptera, suborder Aprocrita, supper family Apoidae, family Apidae and one genus *Apis* (Ruttner, 1986, 1987). The bee species used in the study is *Apis mellifera*, the domesticated species in Africa, Asia, Europe and Americas. The continuous evolution and adaptation of *Apis mellifera* to the different environments to which it has been introduced has given rise to many sub species. Two sub species; *Apis mellifera adansonii* and *A. m. scutellata* are reported in Uganda; *A. m. adansonii* spread in the North and Eastern agro-ecological zones while *A. m. scutellata* is spread in the agro-ecological zones of Southern and Western Uganda (Kasangaki et al., 2017).

2.2. Characteristics and behavior of bees

2.2.1 Swarming

New honey bee (*Apis mellifera*) colonies are formed by swarming; a process whereby an existing colony divides into two or more colonies. Swarming is related to ascent of pollen and nectar flow (Hepburn, 2006). Swarming bees fly temporarily then cluster on shrubs or tree branches where it stays for a few hours or days depending on the weather conditions (Seeley & Visscher, 2003). When a large number of scout bees approve a potential nest site, the whole swarm flies into it (Seeley & Visscher, 2003). Beekeepers use different technologies to manage swarming because swarming colonies become smaller and produce less honey than non swarming colonies (Farrar, 1937).



Plate: 2-1 Swarm cluster of honey bees

2.2.2 *Abscending*

Abscending is the movement of a whole colony from the maternal site to another place leaving empty combs (Hepburn, 2006). Abscending can either be disturbance induced (predation, manipulation, declined quality of nest-site or resource depletion) or resource dearth induced by prolonged wet seasons or overheating during the dry seasons (Winston et al., 1978; Hepburn, 2006). According to Mutsaers (2010), seasonal management based on local conditions can reduce abscending of honey bee colonies.

Honey bees migrate and this involves seasonal movement of bees predicted by resource dearth, wide spread depletion of pollen and nectar associated with high temperature, extreme aridity or rains or cold (Hepburn, 2006) only to return later. Studies by Schneider & McNally (1992) in Okavango River Delta, Botswana, reported migration of honey bees feasible in colonies possessing appropriate population size and age structure that could compensate natural attrition of older worker bees during the migration and sufficient food reserves for long distance travel and establishment of a new nest.

2.2.3 Foraging behaviour

The diet of honey bees consists of protein rich pollen and sugar rich nectar collected separately or synchronously from flowers by foraging worker bees. These resources are collected in quantities that exceed colony demands and are stored for dearth periods; the nectar is converted into honey and pollen stored as bee bread (Nicolson, 2011; Anderson et al., 2014). Studies have been done on foraging behavior of bees (Verma & Dulta, 1986; Abou-Shaara, 2014; Aryal et al., 2016). Abou-Shaara (2014) presents a review on foraging activity including the regulation of foraging tasks, factors impacting this behavior, foraging preference, variations between species and possible methods of controlling the behavior.

Aryal et al. (2016), in Nepal studied foraging behavior of two bee species on buckwheat; *Apis mellifera* L. and *Apis cerana* F. In their findings *A. cerana* F was 1.8% efficient on foraging duration than *A. mellifera* L. and the authors suggested cultivation of buckwheat combined with beekeeping of *A. cerana*. Studies by Verma & Dulta (1986) on foraging behavior of *A. mellifera* L. and *A. c. indica* on pollinating apple flowers where the authors compared the foraging times, peak foraging time, number of nectar foragers and pollen foragers *A. cerana* started foraging earlier and stopped later in all the three altitudes where the study was conducted as compared to *A. mellifera*.

2.3 Beekeeping as an income generating activity

Apiculture or beekeeping is an art and science of collecting, processing honey bee colonies of desired species having them in specified standard boxes, installing at appropriate sites and harnessing both direct and indirect benefits (Sain, 2017). Honey bees are managed as required for either commercial pollination services or production of different bee products i.e. honey, propolis, bees wax, royal jelly (Sain, 2017).

Abere and Lameed (2012) reported that beekeeping as the main occupation for 20% of the apiculturists in Nigeria, while for 80% of the apiculturists it was a secondary occupation. Ezekiel et al. (2013) report that, most of the beekeepers in Ogbomoso Agricultural zone in Nigeria are medium scale producers. Vural & Karaman, (2010) in Turkey where honey production has an important place, reported beekeeping as the main source of income for 68.4% beekeepers who

owned more than 160 colonies, while beekeepers with less than 50 hives earned up to 34% of total income from honey production.

2.3.1 Equipment (types of bee hives and their numbers)

Bee hives are hollow containers that are purposely made to house bees so that their honey can be collected. The east African beekeepers use three types of bee hives; traditional (local) hives, Kenyan top bar (KTB) hive and Langstroth hive (Kajobe et al., 2009; McMenamin et al., 2017). Traditional beehives have fixed combs as in a wild colony. The KTB hives employ top bars, the bees are encouraged to construct their combs along the bars enabling the beekeeper to lift combs for inspection while Langstroth hives consist of movable frames; their expandability can be achieved by addition of boxes on top of existing ones.

The local bee hive usage in Uganda is reported to be higher than modern bee hives and the local hives tend to be more colonized than modern hives (Kugonza & Nabakabya, 2008; Ndyomugenyi et al., 2015). In a study done in Uganda by Kugonza & Nabakabya (2008), 80% of beekeepers in Luwero had top bar hives, while in Katakwi, Bushenyi and Kitgum traditional fixed comb bee hives were used.

In a study on effect of numbers of old type (local) and new type (modern) hives on honey production in Turkey by Vural & Karaman (2010), 1% increase in old type hives caused a decrease of 0.29% in honey production and 1% increase in new type hives caused a 0.47% increase in honey production. Wambua et al. (2016) assessed the performance of frame hive and traditional hive beekeeping in Kenya and found out that honey production was high in traditional hives compared to Langstroth hives and farmers with traditional hives earned more than those with modern hive technology. Beyene et al. (2015) reported no variation in honey production for traditional hives between sites and generally higher in honey production for different hive types, suggesting that location and hive type interaction have significant effect on honey production per hive in Ethiopia.

2.3.2 Education level, training and beekeeping experience

Education increases the ability of a farmer to access information relevant to the enterprise. Modern apiculture requires skilled training and reading manuals for proper understanding of the operations (Ajao & Oladimeji, 2013). Several studies have reported a number of beekeepers not having received any education. Ajao & Oladimeji (2013) reports low literacy rate among bee farmers in Nigeria and this could have affected their chance of shifting from traditional to modern beekeeping. Studies of Abejew & Zeleke (2017) in Ethiopia, reported 26% of the respondents not having received any education. Amulen et al. (2017) reported that beekeepers in Uganda were significantly less educated than their non beekeeping counterparts. In Kenya, Berem et al. (2011) reported formal education of the beekeepers negatively influenced value addition to honey.

According to Sain (2017), having a degree or higher qualification is not essential for one to work in the beekeeping profession and that apiarists can be developed and trained. The inability of beekeeping to improve the status of beekeeping households in Uganda is in part attributed to lack of training in bee husbandry (Amulen et al., 2017). According to Amulen et al. (2017), beekeeping extension services in Uganda are mainly provided by NGOs and government agricultural extension department; in their findings most beekeepers in Northern Uganda had had only one day's training delivered in a classroom without practical exposure. In Kenya, Musimba et al., (2001) reported that lack of extension contributes to low levels of production; only 5.2% of the respondents had been trained in modern beekeeping and traditional harvesting methods were the indicators. Poor honey extraction methods such as boiling of honey combs, sun heating of combed honey are seen as result of a weak extension in Uganda (Kugonza & Nabakabya, 2008).

Experience is another valuable asset in farming as it leads to improved skills and management of the enterprise. The higher the number of years spent in farming by a farmer the more he becomes aware of the new production techniques (Iheaco, 2000). For instance studies by Abejew & Zeleke (2017) in Ethiopia found a positive correlation between beekeeping experience and usage of improved technologies. In Swaziland, Masuku (2013) reported that increase in beekeeping experience increases production of honey. In his findings 1% increase in beekeeping experience resulted in 0.41% increase in honey production. Studies in Uganda have reported the beekeeping

sector having experienced beekeepers. Mujuni et al. (2012) reports most beekeepers with a beekeeping experience of less than 6 years, with 15% having a beekeeping experience of over 16 years. Studies by Kalanzi et al. (2015) in western Uganda showed that 43.5% had spent over 10 years in beekeeping.

2.3.3 Markets and marketing of honey

Uganda has two Honey markets; international and local. Uganda is one of the African countries that is allowed to supply honey to the EU (CBI Market survey, 2009b; Uepb, 2005). The local market provides the largest market for honey in Uganda's shops and supermarkets, the requirements for this market are ability to supply in quantities, packaged and labeled (CBI Market survey, 2009b). Due to the high demand of honey in the local market, Uganda imports honey from neighboring countries eg Sudan and DRC (Jackson, 2004). CBI Market survey (2009) reports consumer preference in the EU for light colored honeys to tropical honeys that are usually dark.

2.4 Honey bee pests affecting honey production

The honey bee insect pests belong to the orders; Lepidoptera, Coleoptera, Diptera, Hymenoptera and Isoptera (Sarwar, 2016). The common honey bee insect pests of the honey bee worldwide and their harmful effects were reported by Sarwar (2016) and Wolfgang & Akwatanakul (2006). The most important of these are those that destroy combs, stores, hives and predators that take foragers as they leave the hive or parasites that raise their offspring in bodies of bees (Sarwar, 2016). The presence of most of these pests has been reported on the mainland of Africa (Pirk et al., 2016). Kajobe et al. (2009) reported twelve pests in Uganda's honey bees; beekeepers perceived small hive beetles, wax moth, small black and red ants, as the most important pests causing economic losses, while spiders, termites, birds, lizards, snakes and rats as less important pests.

Beetle species affecting honey bee colonies were reported in the neighboring Kenya (Torto et al., 2010; Fombong et al., 2012). Torto et al. (2010) in Kenya reported small hive beetles (*Aethina tumida*) in all surveyed colonies and *Oplostomus haroldi* was reported for the first time as a pest of African honey bees. Fombong et al. (2012) reported *Oplostomus fuliginosus* scarabidae beetles for the first time in Kenya's honey bee colonies and the distribution of the two scarabidae beetles

O. fuliginus and *O. haroldi*. In their findings *O. haroldi* was present in Kenya's coastal areas and highlands. Studies under laboratory conditions by Fombong et al. (2012) in Kenya and Donaldson (1989) in South Africa demonstrate that *O. haroldi* and *O. fuliginus*, respectively require decomposing plant material and herbivore (preferably cattle) dung for oviposition and development. Both species of large hive beetles, feed on brood (open and sealed), pollen and honey (Donaldson, 1989; Fombong et al., 2012).

The death head hawk moth, *Acherontia atropos* is identified by the skull design on the thorax (Zagorinsky, Zhantiev, & Korsunovskaya, 2012). They are known to invade honey bee colonies for nectar and honey (Kitching, 2003, 2006). *Acherontia atropos* was at first reported not to cause any obvious damage to a bee colony but recent reports by Sarwar (2016) show that in large numbers, *A. atropos* are capable of depleting hive resources and may cause a colony to abscond.

Bee pseudoscorpions (*Ellingsenius spp.*) are widely distributed throughout Africa (Fombong et al., 2016). *Ellingsenius indicus* in the Himalayas, although they may eat *Varroa* mites, preferred bee larvae, bee lice and remains of dead bees (Thapa et al., 2013). Fagan et al. (2012) used another species of Pseudoscorpions in Newland which preferred *Varroa* mites and even removed mites from bee larvae. van Toor et al. (2015) confirmed that bee pseudoscorpions do eat *Varroa* mites and are potential biological agents for management of *Varroa* mites in honey bee colonies (Donovan & Paul, 2015).

The existence of *Varroa* on the African continent is confirmed in 20 out of 54 countries (Mumoki et al., 2014). Its presence was reported for the first time in South Africa (Allsopp et al., 1997) and later reported in Tanzania and Kenya (Fazier et al., 2009), Ethiopia (Desalegn, 2014), Uganda (Kasangaki et al., 2016). Studies have confirmed contribution of *Varroa* mites to colony losses in the northern hemisphere (Guzmann-Nova et al., 2010, Topolska et al., 2010, Vanengelsdorp et al., 2011). Studies by Muli et al. (2014) in Kenya reported that the presence of *Varroa* alone does not impact on honey bee colony sizes. Chemurot et al. (2016) reported that colony productivity and strength in Uganda were not correlated with mite infestation levels. The implications of this is that other factors acting singly or in combination with *Varroa* infestation levels may be responsible for effects on honey bee colony sizes and productivity.

The exiting literature shows pests, parasites and pathogens that have impacted on honey bees in Europe and America existing in Uganda but there are knowledge gaps on their occurrence, geographic distribution and effect on honey production.

2.5 Viruses affecting honey production in African honey bees

Honey bees are hosts of around 18 identified bee viruses (De Smet et al., 2012); most of them are single stranded RNA viruses belonging to Order Picornavirales (five families), two of which (Iflaviridae and Dicistroviridae) contain the common bee viruses. Multiple virus infections where individual honey bees harbored viruses simultaneously was reported by Chen et al. (2004). Honey bee viruses associated with varroa mites are an increasing interest to researchers and beekeepers.

The following bee viruses have been reported on the African continent: viruses belonging to family Dicistroviridae (acute bee paralysis virus (ABPV), Israeli Acute Bee Paralysis (IABP) Black Queen Cell Virus (BQCV) and family Iflaviridae (Deformed Wing Virus (DWV) Sacbrood Virus (SBV), *Varroa destructor* Virus-1 (VDV-1), and Kakugo virus). Most of these viruses have been observed to be disseminated within and between colonies by *Varroa destructor* (De Miranda et al., 2013; Genersch & Aubert, 2010).

Sacbrood Virus (SBV) infects larvae of the honey bee and results in failure to pupate and death (Bailey, 1975; Mingxiao et al., 2013). An ecdysial fluid rich in sacbrood virus accumulates beneath the unshed skin of the pre-pupae forming a sac from which it derives its name (Bailey, 1975; Grabensteiner & Ritter, 2001) and after the brood has died it becomes dark brown and dries to a flattened gondola shaped scale (Bailey, 1975). SBV may also infect adult bees but obvious physical signs may be lacking (Bailey, 1975). Its presence on the African continent has been reported; in Kenya by Onyango et al. (2016), in North Africa (Algeria, Egypt, Tunisia) by Hussein (2001), in South Africa by Grabensteiner & Ritter (2001).

The presence of the Black Queen Cell Virus, (BQCV) in Africa was reported by; Strauss et al. (2013) in South Africa, Mumoki et al. (2014) and Muli et al. (2014) in Kenya. Kajobe et al. (2010) in Uganda reported the presence of BQCV in adult bees and bee larvae in seven zones and most prevalent in honey bee colonies in Western highlands agro-ecological zone. The posi-

tive samples in the studies of Kajobe et al. (2010) and Muli et al. (2014) came from asymptomatic colonies demonstrating that the presence of BQCV does not necessarily result in overt disease. The viral infections of BQCV and DWV in Kenya did not negatively impact on colony size (Muli et al., 2014). In South Africa, Davison et al. (2003) linked BQCV to increased honey bee mortality when associated with *Varroa destructor*. de Miranda et al. (2013) showed that BQCV is associated with Nosema disease and *V. destructor*. Chantawannakul et al. (2006) detected BQCV in *Varroa* mites in Thailand suggesting their possible vectoring. When BQCV was detected by Kajobe et al. (2010), *Varroa* had not been reported in Uganda's bee colonies. Serious consequences are expected of BQCV disease after the detection of *Varroa* in the districts endemic with BQCV (Kajobe et al., 2010; Kasangaki et al., 2016).

Israeli Acute Bee Paralysis, (IABP) is a distinct marker of honey bee colony collapse disease (CCD) (Di Prisco et al., 2011). It was first reported in Israel where CCD wiped out honey bee colonies on a large scale (Palacios et al., 2008). The symptoms of the disease are trembling wings that progress to paralysis and eventual death in few days (Palacios et al., 2008). IAPV is vectored by *Varroa* mites (De Miranda et al., 2013; Di Prisco et al., 2011). Di Prisco et al. (2011) in their studies in Italy, on the role of *Varroa* mites in transmission of IAPV in honey bees provided the first evidence that *Varroa* is IAPV replication-competent and is capable of vectoring IAPV in honey bees. The presence of IAPV on the African continent was reported; in South Africa by Mumoki et al. (2014b) and Strauss et al. (2013).

Deformed wing disease is caused by Deformed Wing Virus (DWV). The DWV disease is closely associated with honey bee Colony Collapse Disease CCD induced by *V. destructor* (de Miranda & Genersch, 2010). The symptoms of the disease are pupal death and adult bees emerging with deformed wings, reduced size of emerging adult, swollen and shortened abdomen, discoloration and adult death (de Miranda & Genersch, 2010; Mumoki et al., 2014a). The presence of DWV on the African continent was reported; in Kenya (Muli et al., 2014; Mumoki et al., 2014b; Onyango et al., 2016). DWV was detected among the viruses circulating in Kenya's honey bee colonies (Onyango et al., 2016). Muli et al. (2014) showed that viral infections by DWV were not correlated with colony size therefore did not impact on the Kenya's honey bee colonies.

The *Varroa Destructor Virus-1*, (VDV-1) disease is transmitted by *Varroa destructor* (de Miranda et al., 2013). Ongus et al. (2004) in the Netherlands, demonstrated that VDV-1 replicates in *V. destructor* just as the DWV. Phylogenetic analyses showed that VDV-1 is related to DWV and Kakugo Virus (Ongus et al., 2004). Zioni et al. (2011) in their studies in Israel found VDV-1 and VDV-1-DWV recombination in the heads of symptomatic bees and suggested that VDV-1 may be involved in inducing deformed wing pathology. The presence of VDV-1 on the African continent was reported by Strauss et al. (2013) and Onyango et al. (2016). Onyango et al. (2016) found VDV-1 among the viruses circulating in Kenya's honey bee colonies. Strauss et al. (2013) in South Africa found VDV-1 in honey bee colonies but no colony loss was directly attributed to *Varroa* presence or associated pathogens. The presence of Kakugo Virus in the African bees was reported in Kenya (Onyango et al., 2016).

Acute Bee Paralysis Virus (ABPV) affects colonies infested with *Varroa*, the presence of ABPV on the African continent was reported in South Africa (Govan et al., 2000), in Kenya (Muli et al., 2014). ABPV was not detected in the studies of Onyango et al. (2016) in Kenya.

2.6 Important plants for honey production

The diet of honey bees consists of protein rich pollen and sugar rich nectar collected separately or synchronously from flowers by foraging worker bees; the nectar is converted into honey and pollen is stored as bee bread in the hive (Nicolson, 2011; Anderson et al., 2014). Not all flowering plants are beneficial to the bees, some plant nectars are toxic to the bees and are not visited, e.g. *Astragalus miser* v. *serotinus* (Fabaceae) (Majak et al., 1980). Bendifallah et al. (2013) in their studies in Egypt on potential honey plants found Coriander, *Coriandrum sativum* less frequently visited by the honey bees than the solitary wild bees *Andrena cinerea*. Munyuli (2011) studied the role of local and environmental factors on the visitation intensity of different bee species to coffee flowers in central Uganda and recommended farmers to locate their farms next to forest habitats or natural habitats to receive high bee visitations.

Most tropical plants flower discontinuously with a tendency to flower in a particular season; in the rainy seasons flowers are abundant and bees do not have to travel long distances to find food. In drought, flowers are scarce, bees travel long distance to find food and they risk getting lost or die while foraging and the population of bees in the hive is lower (Novais et al., 2009). Identify-

ing honey bee floral sources specific to a region is essential for high honey production and selection for suitable apiary sites (Abou-Shaara, 2015). So far melliferous plants are not well studied in Uganda.

Attifield (2001) gives a list of melliferous plants of tropics and subtropics; Kajobe (2006) in his studies on pollen loads of *Apis mellifera* and stingless bee foragers in Bwindi Forest in Uganda, lists plant species (*Bidens pilosa*, *Carapa grandifolia*, *Croton macrostychus*, *Entandrophragma excelsum*, *Markhamia lutea*, *Prunus africana*, *Syzgium guinense*, *Vernonia sp*) heavily visited by honey bees and also showed that the pollen diet changes over seasons which he attributed to alternating nature of flowering plants. Kajobe et al. (2009) in their studies in Uganda, on flowering periods of important bee forage plants in relation to honey flow periods lists plants used by the bees in Western highlands and eastern agro-ecological zone.

Studies of Larinde et al. (2014a) on bee foraging plants in Nigeria found the most utilized plant species as *Aspillia Africana*, *Emilia sonchifolia*, *Solenostemon monstachyus*, *Talinum triangulare*, *Tridax procumbens*. The most visited family was Asteraceae 23.8%, followed by Anacaraceae (9.5%), Rutaceae (9.5%), Lamiaceae (4.76%) and Curcubitaceae (4.76%). Manuals of useful bee plants have been produced (Latham, 2002b, 2002a). The manual by Latham (2002a) has useful plants in Umalila in Tanzania; many of the plants mentioned are present in the uplands of Central and Eastern Africa. Latham (2002b) also produced a manual of some useful bee plants of the Bas-Province in the Democratic Republic of Congo; most plants mentioned are present in the humid zones of African tropics.

Studies by Abdullahi et al. (2011b) in Nigeria show bee forage plants not evenly distributed in the entire surveyed locations. According to the findings of Beyene et al. (2015) where they evaluated transitional and modern hives for honey production; location and hive type interaction had significant effect on honey production per hive. This finding they attributed to differences in type of bee forage, bee management practice and environmental factors such as climate, pests, predators and disease. There is also knowledge gap on the important plants in the different zones contributing to honey production and interaction between the location and the existing pests, parasites, pathogens and honey production.

2.7 Good beekeeping management practices

Bee management is either professional or small scale. In Professional management, beekeeping is your business, its full time or close to full time whereas in small scale, beekeeping makes less than 50% of your income. Much of Africa's beekeeping is small scale. Traditional bee hive usage is high (Kugonza & Nabakabya, 2008; Kilimo Trust, 2012), colonies are sited in trees and are not moved to exploit multiple forage resources.

Professional beekeeping deals with high production of quality bee products. Haftom & Awet (2013) in Ethiopia reported productivity of modern frame hives at 22.8 (Kg/hive) and KTBH (17.8Kg/hive), Kilimo Trust (2012) in Uganda report a high productivity potential of modern frame hives with high production gaps, implying adoption of modern technologies in the management of frame hives to fill the production gap.

There are new pests, diseases, pathogens in Africa (Kajobe et al., 2016; Onyango et al., 2016; Pirk et al., 2016). In professional beekeeping, diseases and epidemics are of real concern; two breeding successes are reported by Rinderer et al. (2010) for development of honey bees of commercial quality that don't require pesticides for treating or control of *Varroa* mites. Calis et al. (1999) reported an effective biotechnical control for *Varroa* mites using drone brood invasion to trap mites. Chelifers (Arachnida: Pseudoscorpionida) commonly known as bee pseudoscorpions do eat *Varroa* mites (Fagan et al., 2012; van Toor et al., 2015) and are potential biological agents for management of *Varroa* mites in honey-bee colonies. Methods for culturing bee pseudoscorpions have been developed to provide specimens for research and introduction into beehives (Read et al., 2014). Bee pseudoscorpions are widely distributed throughout Africa (Fombong et al., 2016) and their presence in bee hives gives a potential to exploit them in the management programs of *Varroa* mites.

In Uganda policy, initiatives in the agriculture sector have been tailored towards transforming the sector from subsistence to commercialisation; production of food, livestock and fish for sale (Ministry of Agriculture Animal Industry and Fisheries, 2013). Pollination of crops in Africa is adequately provided by nature (Bosselmann & Hansted, 2014). With the shift from subsistence to commercial agriculture pollinator deficits will be realised in agricultural fields. Professional beekeepers in developed countries utilise this opportunity by developing colonies for commercial

pollination. In North America, the pollination of almonds contributes 44.6% of the pollination fees to the commercial pollination industry while sunflower contributes 16.8% (Bond, Plattner, & Hunt, 2014). In Africa, pollination pay schemes are developed in South Africa (Bosselmann & Hansted, 2014).

Naturally honey bees rear new queens to replace a failing queen (queen supercedure) and populous colonies preparing to swarm, rear numerous swarm cells when the mother queen is still in the colony (Wilkinson & Brown, 2002). Professional beekeepers practice queen rearing; to replace old queens, increase number of colonies for commercial production of queens. Several queen rearing methods have been developed; Wilkinson & Brown (2002) describe a method of rearing queens in a queenright colony originally used by National Bee unit for royal jelly production with some modifications. A range of recommended modern queen rearing methods currently in use are reviewed in B  chler et al. (2013).

Bee breeding refers to a set of activities aimed at genetic improvement of a honey bee population such that colonies in every new generation express better traits. It requires controlled matings of queens with selected drones while preserving desired characteristics of beekeepers. The concept behind bee breeding programs is discussed by Uzunov, Brascamp, & Buchler (2017) using the example of the German bee breeding program of breeding for the hygienic behavior against the varroa mite. Where there is no active breeding and selection, the bee species is considered wild. Domestication of honey bees is perceived in the USA where queen breeders supply the whole continent with bred queens (Blacqui  re & Panziera, 2018).

2.8 Situation of Honey production in Uganda

A honey value chain analysis was conducted in Uganda by Kilimo Trust (2012), in their findings the West Nile region, and Western Uganda were the leading producers of honey. Northern Uganda records 640 MT of honey annually while central region has the least 85MT (Kilimo Trust, 2012; MAAIF/UBOS, 2010). In their findings honey production in Uganda is still low and unable to meet the domestic demand making the country unable to meet the required supplies in the EAC and the regional market.

There is no available literature on bee breeding and selection in Uganda, implying that the bee colonies are wild species not domesticated. Beekeepers depend on natural swarming to colonize hives. Most Uganda's honey is organic and meets the European market requirements. According to PMA (2011), the demand for honey was at 3600 MT while the annual production was at 1,538 MT leaving a deficit of 2,062 MT/per annum. The supply gap gives the opportunity to boost the sector to increase production and incomes.

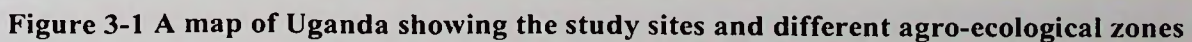
The most recent livestock census MAAIF/UBOS (2010) reported 750,000 hives in Uganda with 65.5% of them colonized. While 87.3% of the total hives are traditional hives and the rest are KTB and Langstroth hives. The baseline findings of Kilimo Trust (2012) also quote current productivities of the different hives varying according to hive type traditional, KTB, and Langstroth; 5 Kg/hive/season, 12 Kg/hive/season, 14 Kg/hive/season respectively, while their potential productivities are 15 Kg/hive/season, 26 Kg/hive/season, 60 Kg/hive/season respectively thus the yield gaps of the three hives are 67%, 54%, and 77%, respectively. Traditional hives despite the yield gap are the most preferred probably due to their low cost.

2.9 Conclusion

This survey on existing literature shows that the beekeeping sector in Uganda is affected by low production and the bee species kept are wild. The exiting literature also shows that pests, parasites and pathogens that have impacted on honey bees in Europe and America exist in Uganda but there are knowledge gaps on their occurrence, geographic distribution and effect on honey production. As much as Muli et al. (2014) says that East African honey bees appear to be resilient to pests, parasites and pathogens, information is lacking on their contribution to the low honey production. There are also knowledge gaps on the impact of existing bee viruses on colony strength in African honey bees. According to Beyene et al. (2015) location and hive type interaction in Ethiopia has significant effect on honey production per hive; knowledge gaps exist on interaction between the location and existing forages, pests, parasites, pathogens and honey production. Understanding these knowledge gaps can bring us closer towards achieving the solution to honey production increase.

MATERIALS AND METHODS

Uganda lies in East Africa within latitudes $4^{\circ}12'$ N and $1^{\circ}29'$ S and longitude $29^{\circ}34'$ E and $35^{\circ}0'$ E. It is bordered by Kenya to the east, South Sudan to the North, Democratic Republic of Congo to the west and Rwanda and Tanzania to the south. The country is divided into ten agro-ecological zones basing on the vegetation cover, climate, landscape and land use activities (Figure 3-1). This study was done in four out of the ten agro-ecological zones in Uganda: Kyoga plains, Mid North, Lake Victoria crescent and Western highlands



Eastern (Kyoga plains) agro-ecological zone is characterised by two rainy seasons in the southern part, with the main rainy season occurring from March to May, peaking in April, and secondary rainy season from August to November with a peak in October/November. The main dry season is from December to February, and secondary dry season is in June and July. Temperature ranges from 15–32.5 °C. The study sites in this zone were in Tororo District located at 00° 45'N, 34° 05'E. The Altitude ranges from 914 – 1,800 Meters above Sea Level (m.a.s.l). The population of Tororo District in 2014 was estimated at 517,080 people (UNBS, 2017e). Here agriculture is the main economic activity with emphasis on food crops millet, cassava, potatoes, and beans, sunflower. The cash crop grown are cotton and onions. Most of the district's agriculture produce is either consumed locally or sold in urban areas within the district (www.tororo.go.ug/economic-activities, https://en.wikipedia.org/wiki/Tororo_District).

The Mid North agro-ecological zone has one rainy season of about seven months, from April to late October with the main peak in July/August and a secondary peak in May, with one long dry season of about four months from mid-November to late March. The driest months are from December to February. The temperature ranges from 15 - 32.5 °C. The altitude ranges from 975 – 1,524 m.a.s.l (UNBS, 2017c). This zone has large wetlands and savannah grasslands with scattered indigenous trees and shrubs interspersed with settlements. Agriculture is the main source of livelihoods and income. The main cultivated crops are sesame, cassava, pulses and sun flower. In addition Apiculture is practiced as an income generating activity. The study sites in this zone were located in Kole (2° 24'N, 32° 48'E) and Lira (2° 20' N, 36° 06' E) Districts. According to the most recent national population census, the population size of Lira District was 408,043 people and that of Kole is 239,327 (UNBS, 2017).

The Lake Victoria Crescent agro-ecological zone covers much of Central Uganda and extends 48 Km to 74 Km inland from Lake Victoria. The zone is characterized by extensive wetlands, short grass and semi deciduous thickets. The study sites were in Nakasongola District, located at 1° 18' N, 32° 30'E at elevation of 1,160 m.a.s.l. The population size of Nakasongola District in 2014 was at 181,795 people (UNBS, 2017a). The annual rainfall received is low and it follows a bimodal pattern with prolonged dry seasons. Nakasongola district lies within the Uganda cattle corridor (Kisaalita & Sempira, 2017). The major economic activity is agriculture with most households engaged in pastoral livestock production, apiculture and subsistence crop farming.

The Western highlands agro-ecological zone lies in the highlands of Rwenzori Mountains in Toro sub region, Western Uganda. The zone comprises of the following districts: Kyenjojo, Kyegegwa, Kamwenge, Kabarole, Bundibugyo, Bunyangabu, Kasese, Ntoroko. The terrain is characterized by undulating hills, forests and thickets. The zone has a bimodal pattern of rainfall with prolonged rain seasons. Agriculture is the main economic activity with most households engaging in livestock and crop farming. Crop farming is mainly subsistence and the main cultivated crops are bananas, beans, maize, sweet potatoes and coffee with commercial tea farms while livestock farming is for commercial dairy production. Apiculture is also practiced as an income generating activity. The study sites in this zone were located in Kabarole (00° 36'N, 30° 18'E) and Kyenjojo (00° 37'N, 30° 37'E) Districts. In 2014 the population was estimated at 469,236 and 422,204 for Kabarole and Kyenjojo respectively (UNBS, 2017d, 2017b).

3.2 Study design

The socio economic study of this thesis was a cross sectional design where observations on the study were analysed from a representative population at a point in time while the other studies (on pests, bee forages and pathogens) were of a longitudinal design where observations were made more than once on a study population over a period of time. In each of the four studied agro-ecological zones one district was selected purposefully based on the honey production records and the number of beekeepers (MAAIF/UBOS, 2010). The study sites/apiaries in each district were selected purposefully with the help of the respective beekeeping extension workers. The sites were decided upon after the apiary owners had demonstrated willingness to participate in the study. Four apiary sites were selected per district and 10% of the honey bee colonies sampled randomly from each apiary.

3.3 Assessment of socio economic factors influencing honey production

A structured questionnaire (Appendix A) was administered in interviews to randomly selected beekeepers from the five districts of Uganda (Kabarole, Nakasongola, Tororo, Kileleshwa and Lira). The instrument was pretested for validity on beekeepers of Osukuru Sub County in Tororo District to ensure that responses from the questions addressed the objectives. The specific methods used are described in details in chapter 4 of this thesis.

3.4 Sample collection and preparation of honey bee pests and parasites

Ten percent of the honey bee colonies in the study apiaries were selected randomly and inspected for presence of different pests and the fate of infested colonies monitored after every four months through hive inspections. During hive inspections, the whole colony including brood was examined for pests and parasites. *Varroa* mites infestation level was measured by the number of mites per 100 bees dislodged with 70% ethanol and visual inspection of 5 cm² of brood, a method adapted from (EFSA Panel on Animal Health and Welfare, 2016). Using standard methods for dry preservation and mounting insects (Krogmann & Holstein, 2010), samples of insect pests of the honey bee and parasites were collected from the inside of in-

festated colonies and kept as dry samples in entomological boxes for further identification and future research (Plate 3-2). The samples of beetles and *Varroa* mites were kept in 70% ethanol.



Plate: 3-1 *Varroa* mites on exposed brood



Plate: 3-2 Honey bee pests collected in this study

3.4.1 Identification of honey bee pests

a) Moths

The moths were identified morphologically, as the Greater wax moths, *Galleria mellonella* using the clumped together pupae cocoons, and by the characteristic webbing and frass associated with their feeding behavior in the standard methods for wax moth research by (Ellis et al., 2013) and Plates 3-3 to 3-5.



Plate: 3-3 Webbing characteristic of wax moth in Hives



Plate: 3-4 Wax moth clumped together pupae cocoons



Plate: 3-5 Adult wax moth

Their larvae were differentiated from the larvae of small hive beetles by the presence of prolegs and absence of a row of spines on the back of their bodies using a small hive beetle identification card (Sagili & Breece, 2016).

The death head hawkmoth (*Acherontia atropos* Linnaeus 1758) was identified using the following morphological characters: the yellow human skull shape on the thorax, the dark brown upper wing with few wavy yellow lines, two large wavy brown lines on the yellow lower wing, the yellow bands on the abdomen, and the high pitched squeak sound made when disturbed.. (Kitching, 2003, 2006; Brehm et al., 2015; Pirk et al., 2016)

b) Beetles

The adult small hive beetles *Aethina tumida* were identified morphologically using the photographic plates in Neumann et al. (2013). In cases where the wax moth larvae were also present in the hive, the small hive beetle larvae were distinguished by their long legs and a row of spines on the back using a small hive beetle identification card (Sagili & Breece, 2016) and described by Sarwar (2016).

The large hive beetles (*Oplostomus haroldi* and *O. fulgineus*) are similar but were distinguished from each other by the prominent stripes on the elytra of the *O. haroldi*, while *O. fulgineus* was

identified using its uniform black colour and the red terminal segment of the antennae (Oldroyd & Allsopp, 2017).

c) Effect of pests on colony strengths and honey production

Colony strength was measured by number of combs covered by bees eight months. A honey bee colony was opened and combs sequentially removed by lifting either frames or top bars depending on hive type. Visual estimates on the percentage of comb occupied by bees on both sides of comb were made as the comb was drawn from the hive. The measurements were done late afternoon when most of forager bees had returned to the hive. This method was adopted from Liebefelder estimation method, that relies on visual estimates on combs by one or more observers in standard methods by Delaplane et al. (2013). A fully covered side of comb was estimated to have 1000 bees (Delaplane et al., 2013).

Honey production was estimated by the apiary owner as the amount of honey harvested per hive in kilograms (Kg). Estimates were obtained from five marked honey bee colonies for three harvesting seasons over two years. This honey measurement method has been used as a proxy for measuring foraging activity, such that if a sufficient honey yield is collected per period then one knows that the colony foraging behavior is proceeding normally (EFSA, 2016).

3.5 Viruses affecting honey production in African honey bees

Sample preparation: Samples of adult worker bees were collected in plastic jars from the inside of honey bee colonies (Plates 3-4). Ten adult worker bees were taken from each sample and transferred into cryo-vials containing RNA-Later to stabilize the RNA while in the field and stored at -20° on arrivals to the laboratory until analysed. A total of 98 samples of 10 adult bees were collected from the seven apiaries. All the adult bee samples used in this study were taken from colonies that had *Varroa* mites.

Pathogen diagnoses: The following bee viruses were screened using Reverse Transcription-Polymerase Chain Reaction (RT-PCR) methods: ABPV, BQCV, DWV, SBV, CBPV, and KBV. Details of the RT-PCR methods used are described in chapter 6.

RNA extraction: Total RNA from the pooled samples was extracted using TRIzol[®] LS Reagent following the manufacturer's protocol. A pooled sample consisted of 10 bees taken from a single honey bee colony.

Primer design: The reverse and forward PCR primers used for BQCV; ABPV; KBV; DWV; SBV and CBPV were according to Antúnez et al. (2006). All the primers were supplied by Inqaba Biotec East Africa Limited.

3.6 Important plants for honey production

3.6.1 Experimental design

A method used by Abdullahi, Sule, & Chimoya (2011a) was adopted for setting experimental plots around each study apiary. Plants seen with flowers within the experimental plots were observed for the presence of foraging honey bees. The target populations were indigenous, agricultural, weed, pasture, and exotic plants. The intensity of the bees visiting flowers of each species was noted. A plant species was scored as a bee forage when at least 10 bees were seen collecting either pollen or nectar within 10 minutes. Observations were done during time of peak foraging activity between 9:00-12:00 hours.

3.6.2 Preparation of plant specimens

A branch of 12-14 inches' length and width not more than 10 inches was collected from shrubs/trees and a whole plant for herbaceous plants including flowers /fruit/pods. The collected specimens were pressed and dried as described by Lacey, Short & Mosley (2001). The plant specimens were identified at the Makerere University Herbarium and deposited at the same herbarium. Details of the methods used are described in chapter 7.

3.7 Data analysis

3.7.1 Assessment of socio economic factors influencing honey production

Data was entered and analyzed using STATA 11 (STATA corp USA). Descriptive statistical analysis was done to determine the characteristics (socio-economic factors) of beekeepers.

Kruskal-wallis test (one way Analysis of Variance) was then done to determine the association of the socio-economic factors that influence honey production of bees as described in chapter 4.

3.7.2 Honey bee pests and parasites affecting honey production in Uganda

All the data in chapter five was entered and analysed in SPSS version 16.0 Descriptive statistics was used to summarize of the number of infested bee colonies, number of pests and co-infestations of pests per hive. Chi square test was used to examine the association between honey production with: colony size, number of pests and pest combinations. The paired sample T-Test was used to compare mean difference in honey production between the start and after 8 months.

The distribution of pests (Figure 5-1) was assembled using Quantum Geographical Information System Computer Software version 2.8 (QGIS Development Team, 2017). The base map was obtained from the GADM database of Global Administrative Areas version 2.0 (GADM, 2012) and added as a vector map layer first. Geo-referenced field data of the incidence of pests was over-laid on the base map and formatted to display the geographic entity that were sampled and pie charts depicting proportionate representation of the pests that were identified.

3.7.3 Assessment of viruses affecting African honey bees

Fisher's exact test of independence of the fife Package (Fife, 2014) in R for statistics computer program (R Core Team., 2014) was used to test whether the number of viruses detected are heterogeneous depending on the honey bee colony strength. Each detected virus was analysed individually and as sum of viruses detected.

3.7.4 Important plants for honey production

All the data were analysed in R version 3.4.4 (details in chapter seven). Pie charts of dominant plant species by family were generated from the data on bee forages. A two way ANOVA was used to determine the variations in plant species dominance cover and average honey harvested and apiary per hive within and between AEZs and apiary sites. The validity of the ANOVA analysis was assessed graphically by inspecting Residuals and was found to be within the acceptable model variation. The ANOVA results were then subjected to TukeyHSD multiple range test was applied to identify which AEZs were actually different from each other in plant species

dominance cover. TukeyHSD multiple range test was also used to compare the average honey production per hive between different sites.

3.8 Limitations of the study, particularly those that restrict the generalisability of the results

The main limitation of the study was the methods designed did not measure how the production of honey was affected and instead the findings were related to colony strength. It was impossible to do a field experiment. The previous colony pest/parasite loads were not controlled and there were co-infestations in honey bee colonies which made it difficult to obtain the contribution of each pest on losses in honey production. The physical counting of each honey bee pest per colony per season was not included in the method which could have later addressed the question of their seasonal populations. The pests kept running away from light when hives were opened making it difficult to count them. The method used in the bee forage study was also limited as it was difficult to compare the contribution of each plant species to honey production as many plants were flowering at the same time.

The data on comb status was not used in the analysis reason being that there were different levels of comb status of; normal, eaten, dry or destruction into debris.

Due to financial constraints in data collection time, the sample size for data of longitudinal study eg day 0, d60, d180, d240 etc. was not adequate for comparison. Therefore I chose to use the start and after data instead, for the analysis. I had been informed by literature of many experiments where a variable of interest had been measured twice from each subject, e.g in nutritional experiments body weight had been measured before a diet was given (initial weight) and at termination of experiment, then the mean weight gain compared between the two groups (Lee, 1978). Pest infestation levels had also been measured before and after exposure to permethrin (Williams et al., 2008)

CHAPTER FOUR

THE SOCIO-ECONOMIC FACTORS INFLUENCING HONEY PRODUCTION IN UGANDA

Agnes S. Otim, Robert Kajobe, Joseph M. Kungu, Richard Echodu. Global Journal of Agricultural Research Vol. 6, Bn. 2 pp 1-9, March 2018

4.1 Abstract

The socio-economic factors of beekeepers influencing honey production in Uganda are fragmentary. A study was conducted to establish the different socio-economic characteristics of beekeeping farmers that influence the production of honey in five districts of Uganda; Lira, Kole, Nakasongola, Tororo, and Kabarole. A structured questionnaire was administered to 218 randomly selected beekeepers from the five districts and data analyzed using descriptives in STATA II and Kruskal-wallis test in SPSS. The results of Kruskal-wallis test indicated seven explanatory variables with P-values of <0.05 influencing honey production namely; district, beekeeping experience, market availability, ranking beekeeping in income generation, types of hives kept per farmer, beekeepers with records and gender. While the following variables were not significant; the beekeeper's level of education, number of colonies kept, age and beekeeping trainings received. These findings can support policy makers, stakeholders and beekeepers on honey production increase. We recommend that beekeeping be prioritized as an income generating activity, link beekeepers to honey markets, encourage record keeping for the beekeepers and beekeeping trainings received by farmers geared towards adoption of modern technologies. We also recommend honey bee colonies to be examined for possible causes of the low production despite increase in number of colonies. The country should promote the use of traditional bee hives and boost their production by making improvements on traditional bee hive designs.

Keywords: Bee hives type, Beekeeper, Environment, Honey bee, colony management

4.2 Introduction

Bee keeping has been promoted worldwide as a major rural development engine with the bee products: honey, bees wax, propolis, pollen, bee venom and royal jelly being of high socio-economic value (Krell, 1996). In Uganda, beekeeping has a substantial contribution towards employment and economy. It is easy and less expensive to operate than any other income generating activity. There is no need to purchase bee feeds as bees collect nectar and pollen from available sources of existing natural bee plants.

The bee hives used range from traditional to modern. The traditional/fixed comb bee hives are of various types depending on the location with locally available materials used for hive construction ranging from bamboo, palm tree logs, twigs to sticks. Two types of modern hives include: Kenya Top bar hive (KTB) and the Langstroth hive. The local bee hive usage is higher than for modern bee hive and the local hives tend to be more colonized than modern hives (Kugonza & Nabakabya, 2008; Ndyomugenyi et al., 2015).

Only 2.7% of the total households in Uganda have been reported to own bee hives, with an estimated annual production of 2,600 tones (MAAIF/UBOS, 2010). The Northern sub region has the highest production while the Central sub region has the least production (MAAIF/UBOS, 2010). The colonization of hives is highest in Eastern (72.1%) and lowest in Karamoja Sub region (60%) (MAAIF/UBOS, 2010).

Apiculture contributes more to household income in Lira District in Northern Uganda compared to other livestock species (Mujuni et al., 2012). In Turkey where honey production has an important place, beekeeping is the main source of income for beekeepers who have more than 160 colonies (Vural & Karaman, 2010). Findings of Abere and Lameed, (2012) in Nigeria show that; beekeeping is the main occupation among 20% of the apiculturists while for 80% of the apiculturists beekeeping is a secondary occupation.

No available literature was found on African studies on this topic. In Turkey there was a parallel honey production increase between 1936-2005 with increase in new type hive numbers; 1% increase in old type hives caused a decrease of 0.29% honey production and 1% increase in new type hives caused a 0.47% increase in honey production (Vural & Karaman, 2010). Beekeepers

with less than 50 hives earn up to 34% of total income from beekeeping, whereas those with more than 100 bee hives earned up to 87.6% of total income from honey production (Vural & Karaman, 2010).

Most farmers in Western Uganda have a beekeeping experience of less than six years, with only 15% having a bee-keeping experience of over 16 years (Mujuni et al., 2012). The findings of Masuku (2013) in Swaziland, linked honey production to beekeeping experience and colony size.

Lack of knowledge and skills and poor harvesting methods are reported as the major limitations to honey production (Ndyomugyenye et al., 2015). Honey extraction methods such as boiling of honey combs, sun heating of combed honey were seen as result of a weak extension in Uganda (Kugonza & Nabakabya, 2008). In Kenya, Musimba et al. (2001) reported that lack of extension services contribute to low levels of production.

Honey in Uganda has two markets: international and local. Uganda is one of the African countries exporting honey to the European Union (EU) market. The local market provides the largest market for honey in Uganda's shops and supermarkets, (Kugonza & Nabakabya, 2008). A national residue monitoring plan is implemented every year in Uganda by the department of livestock health and entomology so as to meet the export markets' requirements of a guaranteed supply of a certain quantity and quality (AAA business bulletin, 2015).

Despite the country's potential in beekeeping with her rich flora and ecological conditions, efforts to up-scale production levels through promotion of traditional bee hives that are cheaper; have not satisfied the growing international market for flavoured and organic honeys (CBI Market survey, 2009a; TUNADO, 2012). It is estimated that Uganda has the capacity to produce 500,000 tons of honey per year (MAAIF/UBOS, 2010). The country's honey production has been increasing though at very low levels according to FAO statistics. The constraints of beekeepers in Uganda have been reported (Kugonza & Nabakabya, 2008; Kajobe et al., 2009; Kalanzi et al., 2015). A number of socio-economic characteristics of beekeepers influencing adoption of modern hives have been documented in other countries (Adgaba et al., 2014; Gebiso, 2015; Kalanzi et al., 2015). Adgaba et al. (2014) in Saudi Arabia, reported education level of a beekeeper as a determinant of adoption of box hive technologies. Gebiso (2015) in Ethiopia, shows the main determinants of adoption of modern hives as farm yard size, number of local

hives beekeepers possessed, participation on demonstration, wealth status of beekeepers and participation of non farm income sources. Kalanzi et al. (2015) in Uganda, reports education and training as socio-economic factors influencing adoption of modern bee hives. In Uganda, the socio-economic characteristics of the beekeepers affecting honey production remain fragmentary and needs to be understood. The aim of this study was therefore to determine the different socio-economic factors of beekeepers under pinning honey production in Uganda and suggest solutions under which policy makers and beekeepers should operate in order to increase honey production.

4.3 Materials and Methods

4.3.1 Study sites

Six cross-sectional surveys with both quantitative and qualitative parameters were conducted in five districts. Kabarole represents the Western highlands, Nakasongola, the Lake Victoria Crescent, Tororo, the Kyoga plains (Eastern) while Lira and Kole represent the Mid North . The study districts were selected basing on the fact that they were good honey producing areas in their agro-ecological zones.

4.3.2 Study design

A stratified random selection technique (based on number of hives owned) was used to select two hundred and eighteen (218) beekeepers from the five districts in Uganda; one hundred seventy five males and forty three females (Table 4-1).

Table: 4-1 Number of farmers (male, female) selected per district

Gender	District					Total
	Nakasongola	Lira	Tororo	Kabarole	Kole	
Male	49	19	39	34	34	175
Female	21	1	10	5	6	43
Total	70	20	49	39	40	218

Numbers in the table represent number of farmers

A structured questionnaire was administered to bee keepers to determine the factors influencing the low production of honey. The socio-economic variables included; the education level, age,

rank of beekeeping in income generation, number of years spent in beekeeping practice, market availability, location or district of origin, keeping records of the beekeeping enterprise and number of trainings in honey production received by the beekeeper. Other aspects included; the type of hives, total number, and number of colonized hives kept per farmer. The questionnaire was pretested for validity on the farmers of Usukuru Sub County in Tororo district to ensure that the questions answered the study objective.

4.3.3 Sample size and sampling strategy

The sample size was determined using the mathematical tables and calculated using the formula by Krejcie and Morgan, (1970)

$$s = \frac{x^2 N \rho (1 - \rho)}{d^2 (N - 1) + x^2 \rho (1 - \rho)}$$

Where;

s = required sample size

x = z value (1.96 for 95% confidence level)

N = population size

ρ = Population proportion (expressed as a decimal) (assumed to be 0.5 (50%))

d = Degree of accuracy 5% expressed as a proportion (0.05) It is margin of error.

4.3.4 Statistical analysis

Data was entered and analyzed using STATA 11 (STATA corp USA). Descriptive statistical analysis was done using frequencies and percentages to summarize the socioeconomic characteristics. Kruskal-wallis test was then done to determine the association of the socio-economic factors that influence honey production of bees.

4.4 Results

4.4.1 Characteristics of the beekeepers

Results of analysis on the characteristics of the beekeepers show that across all the districts, 80.3% of the beekeepers were men and 19.7% women (Table 4-2). Out of the sampled beekeepers 61.4% were over 40 years of age. Majority of the sampled beekeepers (57.9%) kept two or more types of bee hives, 27.3% of the beekeepers had only traditional bee hives, 11.1% of the beekeepers had only top bar hives, while 3.2% kept only Langstroth bee hives. The results on hive types further reveal that; 64.8% of the beekeepers owned between 1-20 bee hives with the majority (82.9%) of the beekeepers having hives colonized (Table 4-2).

The results on the education level show that only 1.4% of the beekeepers had not undergone any formal education, 79.7% of the beekeepers had undergone trainings on aspects of honey production, 52.5% of the beekeepers had a bee keeping experience of between 1-5 years, while 19.6% had an experience of more than 10 years. The results further revealed that; 64.7% of the beekeepers had available markets for their honey, while 11.6% of the beekeepers did not know where to find markets. The ranking of beekeeping as an income generating activity was first in 15.3% of the beekeepers.

Table: 4-2 Socio-economic characteristics of respondents

Explanatory Variable	Category	Frequency	Percentage
Education level	None	3	1.4
	Primary school	80	37.2
	Secondary school	87	40.5
	Tertiary institutions	45	20.9
Gender	Male	175	80.3
	Female	43	19.7
Age (years)	15-30	30	13.9
	31-40	45	20.8
	41-60	98	45.4
	above 60	43	19.9

Explanatory Variable	Category	Frequency	Percentage
District of origin	Nakasongola	70	32.1
	Lira	20	9.2
	Tororo	49	22.5
	Kabarole	39	17.9
	Kole	40	18.3
Ranking of honey production in income generation	1 st position	18	15.3
	2 nd position	33	28
	3 rd position	36	30.5
	4 th position	18	15.3
	5 th position	13	11
Beekeeping Experience (Years)	1-5 years	94	52.5
	6-10 years	50	27.9
	more than 10 years	35	19.6
Types of hives kept per farmer	Traditional hives only	59	27.3
	Top bar hives only	24	11.1
	Langstroth beehives only	7	3.2
	More than one hive type	125	57.9
Total number of hives kept per farmer	1-20	140	64.8
	21-40	49	22.7
	41-60	11	5.1
	60-80	6	2.8
	81-100	5	2.3
	>100	5	2.3
Number of colonized hives per farmer	1-20	179	82.9
	21-40	25	11.6
	41-60	4	1.9
	60-80	4	1.9
	81-100	2	0.9
	>100	2	0.9

Explanatory Variable	Category	Frequency	Percentage
Trained on aspects of honey production	Trained	173	79.7
	Not trained	44	20.3
Market Availability	Yes	134	64.7
	No	49	23.7
	Don't know	24	11.6

4.4.2 Factors that influence honey production

Out of the twelve explanatory variables compared, only seven variables significantly associated with honey production with Kruskal-wallis, P-values of <0.05 (Table 4-3). These seven variables included; gender, district, beekeeping experience, market availability, beekeepers with records, ranking beekeeping in income generation and types of hives kept per farmer. In gender, the mean rank of honey production was highest for males than females. There were also differences in the mean ranks of honey production at districts, with honey production highest in Kabarole followed by Lira, and the least production in Tororo District. The mean ranks of honey production also increased with increase in beekeeping experience. Honey production was also high among farmers who ranked bee keeping as first among the beekeeper's income generating activities. It's important to note that honey production was high among farmers keeping only traditional hives and those who kept more than one hive type as compared to those who had only modern bee hives. The production high among farmers who kept records of their beekeeping enterprise and those with available markets for bee products. The following variables were not significant in influencing honey production: age, education level, training in aspects of honey production and total number of hives kept and number of hives colonized (Table 4-3).

Table: 4-3 Honey production in relation to socio-economic factors of respondents

Explanatory variable	Category	Mean Rank	χ^2	P
Education level	None	109.8	3.8	0.279
	Primary	102.03		
	Secondary	104.9		
	Tertiary	123.9		
Gender	Male	114.3	5.16	0.025
	Female	90.2		
Age (years)	15-30	105.0	1.2	0.758
	31-40	117.2		
	41-60	105.6		
	> 60	108.4		
District	Nakasongola	113.9	70.0	<0.001
	Lira	137.9		
	Tororo	56.8		
	Kabarole	164.8		
	Kole	98.4		
Ranking of bee keeping in income generation	1 st position	88.8	19.8	<0.001
	2 nd position	61.0		
	3 rd position	54.3		
	4 th position	40.5		
	5 th position	56.0		
Beekeeping Experience (Years)	≤ 5 years	70.5	33.7	<0.001
	6-10 years	100.5		
	> 10 years	127.4		
Types of hives kept per farmer	Traditional hives only	113.4	22.6	<0.001
	Top bar hives only	51.4		
	Langstroth bee-	107.6		

Explanatory variable	Category	Mean Rank	χ^2	P
	hives only			
	2 or more hive types	116.3		
Total number of hives kept per farmer	1-20	53.2	29.7	0.00
	21-40	76.6		
	41-60	158		
	60-80	960		
	81-100	299		
	>100	504		
Number of hives colonised	1-20	25.0	9.0	0.109
	21-40	43.2		
	41-60	35.6		
	61-80	49.9		
	81-100	51.4		
	>100	49.4		
Trained on aspects of honey production	Trained	109.7	0.113	0.737
	Not trained	106.2		
Market Availability	Yes	118.7	48.7	<0.001
	No	101.9		
	Don't Know	26.3		
Beekeepers with Records	Yes	116.4	5.2	0.023
	No	97.2		

χ^2 = Kruskal-wallis Chi square and P = P values

4.5 Discussion

To our knowledge this was the first study to report socio-economic factors influencing production of honey in Uganda. Only seven of the twelve socio-economic factors assessed were observed to be significantly influenced honey production. These included; gender, district location, ranking of bee keeping in income generation, types of hives kept per farmer, beekeeping experi-

ence, market availability and keeping records which are in agreement with findings that have been reported in other studies (Vural & Karaman, 2010a; Masuku, 2013b; Kalanzi et al., 2015; Otim et al., 2019).

The findings of this study that show honey production differences between districts suggest location having an influence on honey production. This is in agreement with the findings by Otim et al. (2019) in Uganda, where honey production differences of apiary sites between and within agro-ecological zones which the authors attributed to differences in bee forage and other factors such as pests, pathogens and management

Our results also suggest that beekeepers with only traditional hives produce more honey than those using modern hives (either Kenya Top Bar or Langstroth bee hives) only. This agrees with studies by Kalanzi et al. (2015) which reported that honey production in Kalinzu Forest in western Uganda is highly dependent on the use of traditional bee hives. The low production of modern hives could be explained by the continued use of traditional beekeeping methods in their management. However, these findings are not in agreement with studies in Ethiopia where the average honey productivity of modern hives was found to be higher than local hives and Kenya top bar hives (Haftom and Awet, 2013; Beyene and Verschuur, 2014; Gebiso, 2015). Vural & Karaman (2010), in Turkey, reported a parallel honey production increase between years 1936-2005 with increase in new type hive numbers; implying that hive type has an influence honey production.

The finding that shows the rank of beekeeping as an income generating activity of a farmer strongly influencing honey production, is in agreement with studies of Vural & Karaman, (2010) in Turkey. This could be due to the farmers spending more time managing the apiaries. The findings of this study that show market availability influencing honey production has implications to beekeeping, beekeepers should be connected to markets for increased honey production

Our finding that shows beekeepers keeping records producing more honey compared to those not keeping records, the possible explanation for the this, is that the beekeepers can use the information to tease out causes of losses and rectify them for increased honey production.

The numbers of male beekeepers was predominantly high as compared to the female beekeepers. This finding concurs with the findings reported in studies by Mujuni et al. (2012) and Ndyomugenyi et al. (2015), however the differences in gender significantly influenced production of honey as previously reported by Masuku (2013). The implication of this finding is that beekeeping is an activity that can be done well by men.

The findings that show beekeeping experience associated with honey production, are in agreement with Masaku (2013) in Swaziland, who reported that 1% increase in beekeeping experience resulted in 0.41% increase in honey production. this implies that beekeeping requires experience

The findings of this study have revealed that beekeeping trainings received by farmers in Uganda are not translated to honey production. This could be probably due to laxity by the farmers in applying the knowledge they received during training since 79.7% of the beekeepers had been trained on aspects of honey production. On the contrary, a similar study conducted in Kenya by Musimba et al. (2001) showed that lack of extension services contributed to low levels of production. Kalanzi et al.(2015) in their study in Uganda, reported formal education and training positively correlated to adoption of improved bee hives.

Our findings that show number of colonies not associated with production is opposed to findings of Vural & Karaman, (2010) in Turkey, who reported that increase in number of colonies results in honey production increase. This has implications to our findings; there is a problem with the bee colonies in Uganda which needs to be addressed.

4.6 Conclusion

The socio-economic factors that influenced honey production were gender, district, beekeeping experience, market availability, beekeepers with records, ranking beekeeping in income generation and types of hives kept per farmer. The following socio-economic factors do not influence honey production; age, number of hives kept, number of colonized hives, education level and training in aspects of honey production. The country should up-scale honey production levels by; farmers giving beekeeping an important place among their income generating activities, connect beekeepers to honey markets for increased honey production, record keeping for the beekeepers to tease out causes of losses and rectify them for increased honey production and beekeeping

trainings received by farmers to be geared towards adoption of modern technologies. We also recommend honey bee colonies to be examined for possible causes of low production despite increase in number of colonies.

CHAPTER FIVE

PESTS AFFECTING HONEY PRODUCTION IN AFRICAN HONEY BEES IN SELECTED DISTRICTS IN UGANDA

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5.1 Abstract

The worldwide decline of honey bee colonies blamed on pests is a socio-economic and political pressure on pollination and honey production. We conducted a longitudinal study between April 2014 and May 2016 to assess the diversity of pests influencing honey production in five districts of Uganda; Lira, Kole, Tororo, Nakasongola and Kabarole. The pests were identified using taxonomic keys, extent of infestation and fate of colonies monitored in hive inspections and data analysed using descriptive statistics in SPSS version 16.0 . The most dominant pests included; parasitic mite, *Varroa*, *Aethina tumida*, *Oplostomus haroldi* and *Acherontia atropos*. The *Varroa* mite and *A. tumida* were present across the study districts. The colonies in Lira were the most affected with 85.7% and 78.6% colony infestation with *Varroa* and *A. tumida* respectively. Co-infestations of pests were highest in Lira in 80% colonies and lowest in Kabarole (29.7%). It was observed in this study that pest co-infestations and their increase in populations negatively affect honey bee colony sizes, resulting in reduced honey production. Therefore early detection and target specific control strategies against the identified pests should be employed.

Key words: African honey bee pests, honey production

5.2 Introduction

The honey bees (*Apis mellifera* L.) are economically beneficial insects from which many households have derived their livelihoods. Globally, 30% of the food crops and 90% wild plants are dependent on bees for pollination (Chavaria, 1999). Honey is the bee product traded worldwide and the total world production is estimated at 1,500,000 metric tones. Africa's honey production

is at 198,959 tons (FAOSTAT, 2017) while Uganda's annual production is 712 tones (FAOSTAT, 2013).

The recent reported increased losses of honey bee colonies points to honey bee parasites, pests and diseases (Neumann and Carreck, 2010; Ratnieks and Carrek, 2010). Several honey bee pests and parasites are known to cause colony losses worldwide (Wolfgang & Akwatanakul, 2006; Chantawannakul et al., 2016; Sarwar, 2016). Chantawannakul et al. (2016) reviews pests, parasites and pathogens in Asia, Sarwar (2016) discusses the common insect enemies of the honey bee and their harmful effects. The presence of some of these pests has been reported on the mainland of Africa (Kajobe et al., 2016; Pirk et al., 2016). Pirk et al. (2016) reviews the status of bee health in Africa; the authors discuss the presence of pests, parasites, pathogens and predators. Kajobe et al. (2016) reported pests of honey bees in Uganda causing economic losses.

The Coleopteran pests affecting honey bee colonies reported on the African continent are Small hive beetles (*Aethina tumida*) and large hive beetles *Oplostomus haroldi* and *O. fuliginus* (Ellis, 2003; Torto et al., 2010; Cuthbertson et al., 2013; Fombong et al., 2013). Small hive beetles *Aethina tumida* and large hive beetle species of *Oplostomus* belong families Nitulidae and Scarabidae, respectively (Cosoroaba, Chitimia, & Ilie, 2008; Torto et al., 2010;). Small hive beetles (*Aethina tumida*) and *O. fuliginus* are native to Africa but have spread to other continents (Ellis, 2003; Cuthbertson et al., 2013). The small hive beetles are said to do little damage and are considered to be a minor pest to African honey bee colonies (Torto et al., 2010). *Oplostomus haroldi* and *O. fuliginus* feed on hive resources (pollen, brood, honey) and damage comb structure (Donaldson, 1989; Fombong et al., 2013). According to Fombong et al. (2013), the two related Scarabidae species did not overlap in their geographic range: *O. fuliginus* occurred in semi arid areas whereas *O. haroldi* occurred in coastal areas and highlands of Kenya. The large Scarabidae hive beetle (*O. haroldi*) is 18mm long and is conspicuous in the hive and their colour ranges from solid black to black with orange or red longitudinal stripes (Sarwar, 2016). Sarwar (2016) reported that where 200-300 have been seen in a colony their presence caused the colony to abscond.

The family Pyralidae has two known moth species that cause damage to the bees: the greater wax moth *Galleria mellonella* and lesser wax moth *Achroea grisella* (Sarwar, 2016). Of the two the

greater wax moth is more destructive and their larvae cause damage to combs left unattended to by the bees and ruins combs of weak colonies reducing them to a mass of webs. Within the Sphingidae family of moths, three species of genus *Acherontia* are known to raid honey bee colonies and drink honey directly from the comb; *Acherontia atropos* (African death head hawkmoth), *A. styx* (the lesser death head hawkmoth) and *A. lachensis* (the greater death head hawkmoth) (Kitching, 2006). *Acherontia atropos* are found all over Europe and much of Africa while *A. lachensis* and *A. styx* occur in Asia (Zagorinsky et al., 2012). All the three species can be identified by a human skull mark on the thorax (Zagorinsky et al., 2012; Pirk et al., 2016). A common behavior of these hawkmoths is their ability to make squeak sounds when picked or disturbed or while in the hive (Kitching, 2006).

Ants are known to enter honey bee colonies, remove food and brood and their continued disturbance may cause a colony to abscond (Pirk et al., 2016). The most frequently recorded ant species that are capable of destroying the whole apiary within hours are the weaver ant (*Oecophylla smaragdina*), the black ant (*Monomorium minimum*), safari ants (*Doryllus spp*) and *Formica spp.* (Sarwar, 2016). Studies by Kajobe *et al.* (2009) in Uganda show that ants are among the important pests causing economic losses to bees and traditional hives as vulnerable to attack by black ants.

Studies by Taha & Al-Kahtani (2013) show that honey production is significantly higher in strong than in weak colonies. The reduction in bee populations poses a threat to crops that are dependent on bee pollination and the honey industry. Pests that affect the colony population size need to be identified for their management so as to keep honey bee populations safe which is critical for the honey and the agriculture industries.

The aim of this study was to determine the diversity (species richness and species evenness) of pests responsible for low honey production in Uganda. This study's significance is that it gives a clear understanding on the distribution and magnitude of the honey bee pest problem in Uganda for policy makers to plan for control.

5.3 Materials and Methods

5.3.1 Study sites

This study was conducted in five districts of Uganda; Kabarole Nakasongola, Tororo, Lira and Kileleshwa located in four agro-ecological zones of Uganda; Western highlands, Lake Victoria crescent and Kyoga plains and Mid Northern agro-ecological zones. The study sites/apiaries in each district were selected with the help of the respective beekeeping extension workers. Details of the study sites are described (Kisaalita & Sempira, 2017; UNBS, 2017a, 2017e, 2017d, 2017c).

5.3.2 Research design

The study was longitudinal in which the infestation and fate of colonies was monitored over time. Criterion sampling technique was used to obtain the samples. This involved inspections of honey bee colonies for pests and parasites from weakened and strong colonies. Samples of pests were taken from 10% of honey bee colonies in an apiary. Recording was made on damages of colonies infested and estimated seasonal populations. Both quantitative and qualitative data was collected. Qualitative data was based on observation of colony strengths (bee numbers), comb construction and honey stores.

5.3.3 Data collection (Hive inspection method)

The honey bee pest infestation and fate of colonies was monitored through time by hive inspections in 27 apiaries in a total of 276 honey bee colonies. 10% of honey bee colonies per apiary were marked and inspected for parasites and pests and recordings made on percentage of bee colonies infested and number of observed pest species in a single colony. Samples of honey bee pests and adult bees were picked for identification.

Data collection on *Varroa* mites

a) Brood examination

5 cm² of drone and worker brood comb from each colony were examined for *Varroa* mites. Individual brood cells after removing the capping were examined using a torch; the mites' presence was confirmed by examining the bottom of the cell and the bee brood for attached mites. A re-

cording was made for the number of mites found in every per 5 cm² on brood and *Varroa* mite samples were collected from brood combs using a pair of forceps

b) Adult bee examination

Approximately 100 bees were removed from a bee colony in jars and submerged in 70% ethanol, the container was stirred for 10 minutes and the bee samples separated from the mites using a sieve with a mesh size of approximately 2–3 mm. A recording was made for the number of mites found on 100 adult bees

c) Data collection on Lepidopteran pests

Marked honey bee colonies per apiary were opened and inspected for the presence of moths' pests and the percentage of bee colonies infested recorded. Some adult moths were picked from the inside of infested colonies, stretched and pinned with wings neatly spread on a spreading board in entomological boxes and kept dry for further identification a method adopted from standard methods for dry preservation and mounting insects (Krogmann & Holstein, 2010).

d) Identification of moths

The Greater wax moths (*Galleria melonella*) were identified morphologically using the clumped together pupae cocoons in hives, the characteristic webbing and frass associated with its feeding behavior and adult moths as described in the standard methods for wax moth research by (Ellis et al., 2013). Their larvae was differentiated from the larvae of small hive beetles by the presence of prolegs and absence of a row of spines on the back of their bodies using a small hive beetle identification card (Sagili & Breece, 2016).

The death head hawkmoth (*Acherontia atropos* Linnaeus 1758) was identified using the following morphologically by: the yellow human skull shape on the thorax, the dark brown upper wing with few wavy yellow lines, two large wavy brown lines on the yellow lower wing, and the yellow bands on the abdomen. further identification was made by the high pitched squeak sound made when disturbed as described in (Kitching, 2003, 2006; Brehm et al., 2015; Pirk et al., 2016).

e) Data collection on Coleopteran (beetle) pests

Adult beetles samples were handpicked from the inside of honey bee colonies in labeled sample bottles and preserved in 70% ethanol (ethyl alcohol). The specimens were thoroughly dehydrated by changing the alcohol a couple of times before storing. Some specimens were pinned in entomological boxes and kept as dry samples for identification and reference (Krogmann & Holstein, 2010).

f) Beetle identification

The adult small hive beetles *Aethina tumida* were identified morphologically using photographic plates (Neumann et al., 2013). In cases where the wax moth larvae was also present in the hive, the small hive beetle larvae was distinguished by their long legs and a row of spines on the back using a small hive beetle identification card (Sagili & Breece, 2016; Sarwar, 2016). The large hive beetles *Oplostomus haroldi* and *O. fulgineus* were distinguished from each other by the prominent stripes on the elytra of the *O. haroldi* and the uniform black colour and red terminal segment of the antennae of *Oplostomus fulgineus* (Oldroyd & Allsopp, 2017).

g) Data collection on Formicidae (ant) pests

Honey bee colonies (10%) in each study site were inspected for different ant species. Some specimens were pinned in entomological boxes and kept as dry samples for future identification and reference.

h) Colony strengths were measured by number of combs covered by bees. A honey bee colony was opened and combs sequentially removed by lifting either frames or top bars depending on hive type. Visual estimates on the percentage of comb occupied by bees on both sides of comb were made as the comb was drawn from the hive, a Liebefelder estimation method (Delaplane et al., 2013).

i) Honey production was estimated as an average amount of honey harvested per hive in kilograms (Kg) by the apiary owner from five marked honey bee colonies recorded for three harvesting seasons in duration of two years (EFSA, 2016).

j) **Data analysis:** The data in this chapter was analysed in SPSS. A descriptive statistics using frequency and percentage was used to summarise information on number of infested bee colonies and number of pests. Pearson chi-square test was used to examine for differences of honey bee colonies infested with different pests before and after eight months. The mean difference in honey production was obtained after comparing the production means at the start and after eight months was examined using paired sample T-Test. The association of honey production with: colony size, number of pests and pest combinations was analysed using chi square.

5.4 Results

5.4.1 Honey bee pest species existing in the study areas

Results from hive inspections show 13 pest species found in this study (Table 5-1). The parasitic honey bee mite; *Varroa* was present across the five study districts (Table 3). The presence of *Varroa* mites was high in Lira (85.7% of the colonies), Kileleshwa (85%), Tororo (77.4%), and Nakasongola (64.9%) and lowest in Kabale (58.3%).

Three Coleopteran honey bee pests were present: Small hive beetle (SHB), *Aethina tumida* spp and two large hive beetles (LHB); *Oplostomus fulgineus* and *O. haroldi*. The SHB was present across the five study districts (Table 5-1). Lira had 78.6% of infested colonies, Tororo had 75.5%, Nakasongola 64.5%, Kabale 43.2% and Kileleshwa the lowest (30%) infested colonies. The LHB, *Oplostomus fulgineus* was found in three Districts: Tororo (9.4% of the Colonies), Nakasongola (8.3%) and Lira (2.9%) while *O. haroldi* spp was found in honey bee colonies in only Nakasongola (41.7% of the colonies) and Lira (11.4%) districts (Figure 5-1).

Two Lepidopteran moth species associated with honey bees were recorded: the death head hawk moth species (*Acherontia atropos*) and the greater wax moth (*Galleria mellonella*). Of the two moth species, the death head hawk moth was present only in 4.2% of the colonies in Nakasongola whereas the greater wax moth was found in all the districts except Kileleshwa. Most times the hawk moth were found dead in honey bee colonies probably killed by bees.

Three Formicidae species were identified: Black ants, safari ants and sugar ants. Black ants affected colonies across all the districts whereas safari ants were recorded in Tororo and sugar ants

in Nakasongola (Table 5-1). Termites were found destroying bee hives in Nakasongola, Lira and Tororo. Occasional pests in honey bee colonies included frogs and crickets.

Table: 5-1 Bee pests existing in honey bee colonies of selected districts in Uganda

Existing pests	Propotion of colonies affected n(%)				
	Lira n=70	Kole n=20	Nakasongola n=96	Tororo n=53	Kabarole n=37
<i>Varroa mites</i>	60(85.7)	17(85)	61(64.9)	41(77.4)	21(58.3)
<i>Aethina tumida</i>	55(78.6)	6(30)	60(62.5)	40(75.5)	16(43.2)
<i>Oplostomus fulgineus</i>	2(2.9)	0(0.0)	8(8.3)	5(9.4)	0(0.0)
<i>Oplostomus haroldi</i>	8(11.4)	0(0.0)	40(41.7)	0(0.0)	0(0.0)
<i>Acherontia atropos</i>	0(0.0)	0(0.0)	4(4.2)	0(0.0)	0(0.0)
<i>Galeria mellonella</i>	8(11.4)	0(0.0)	6(6.2)	12(22.6)	3(8.1)
Termites	1(1.4)	0(0.0)	4(4.2)	1(1.9)	0(0.0)
Black ants	7(10)	3(15)	11(11.5)	4(7.5)	1(2.8)
Safari ants	0(0.0)	0(0.0)	0(0.0)	1(1.9)	0(0.0)
Rats	7(10)	2(10)	17(17.7)	3(5.7)	0(0.0)
Cockroaches	1(1.4)	0(0.0)	3(3.1)	1(1.9)	0(0.0)
Sugar ants	0(0.0)	0(0.0)	1(1)	0(0.0)	0(0.0)
Lizards	0(0.0)	0(0.0)	0(0.0)	0(0.0)	2(5.4)

n = number, % = percent

5.4.2 Co-infestations of honey bee pest species

Results on Co-infestations of honey bee pest species Table 5-2; shows up to 6 pests in a honey bee colony in Lira and Nakasongola districts. Co-infestations with 2 to 4 honey bee pests highest in (80.4%) honey bee colonies in Lira and Tororo (69.8%) and lowest in Kabarole (29.7%). A small percentage (12%) of the studied colonies were not infested with pests.

Table: 5-2 Co-infestations in honey bee colonies

No. of pest <i>spp</i> in a bee colony	Lira n(%)	Kole n(%)	Nakasongola n(%)	Tororo n(%)	Kabarole n(%)	Overall n(%)
0	6(8.6)	2(10.0)	10(10.4)	6(11.3)	9(24.3)	33(12)
1	8(11.4)	10(50.0)	25(26.0)	10(18.9)	17(45.9)	70(25.4)
2	38(54.3)	6(30.0)	23(24.0)	17(32.1)	9(24.3)	93(33.7)
3	11(15.7)	2(10.0)	18(18.8)	16(30.2)	2(5.4)	49(17.8)
4	4(5.7)	0(0.0)	15(15.6)	4(7.5)	0(0.0)	23(8.3)
5	2(2.9)	0(0.0)	3(3.1)	0(0.0)	0(0.0)	5(1.8)
6	1(1.4)	0(0.0)	2(2.1)	0(0.0)	0(0.0)	3(1.1)
Total n	70(100)	20(100)	96(100)	53(100)	37(100)	276(100)

n=number of honeybee colonies, %=percent



Plate: 5-1 *Acherontia atropos* dorsal & ventral view

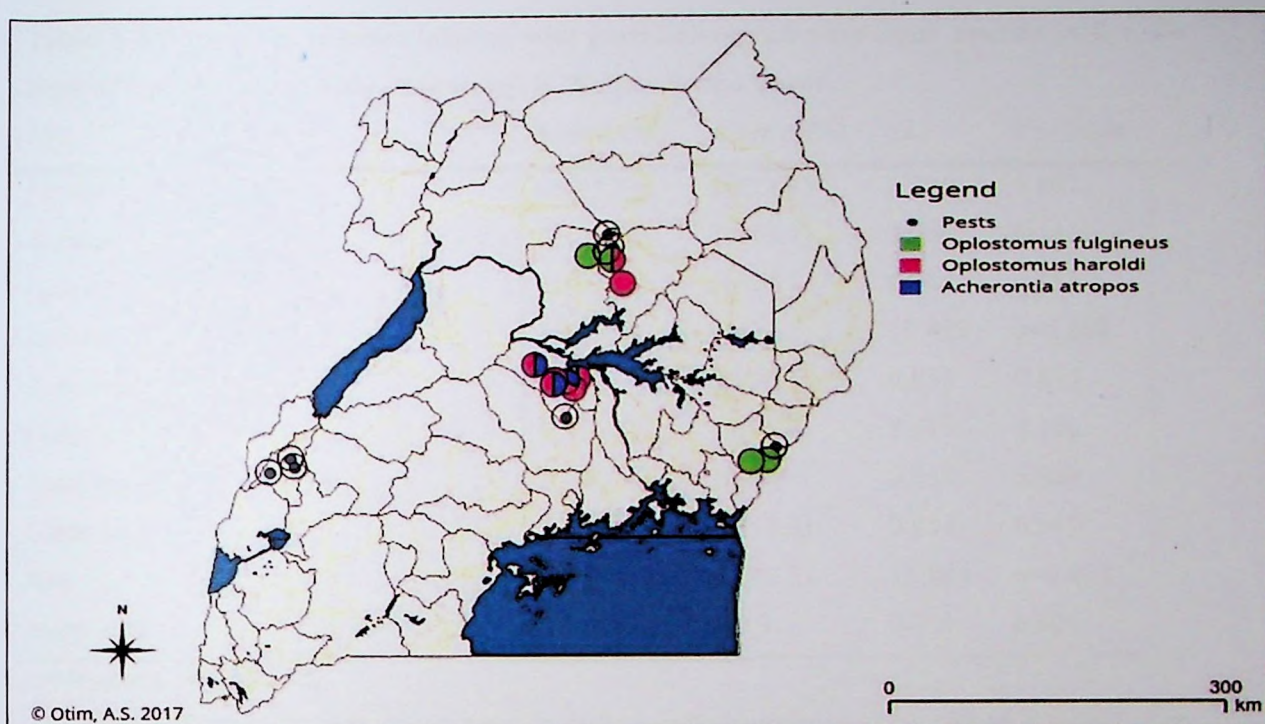


Figure 5-1 The distribution of honey bee pests

5.4.3 Changes in honey bee colonies after eight months

After comparing the numbers of infested colonies before and after 8 months (Table 5-3), there was a significant ($P < 0.001$) increase in number of infested honey bee colonies observed with *Oplostomus haroldi* and rats. There was an observed reduction in number of honey bee colonies infested with *Varroa* mites, small hive beetles and *Oplostomus fulgineus* after 8 months but the figures were small to give significant values. An increase in number of honey bee colonies infested with black ants, and wax moth was observed though the figures were small to give significant values.

Table: 5-3 Number of colonies infested with pests before and after eight months in five districts of Uganda: Lira, Kole, Nakasongola, Kabarole and Tororo

Pest	Start n (%)	After n (%)	χ^2	P – value
<i>Varroa</i>	85(75.2)	80(70.8)	3.356	0.067
<i>Aethina tumida</i>	81(71.7)	72(63.7)	2.166	0.141
<i>Oplostomus fulgineus</i>	11(9.7)	5(4.4)	0.564	0.453
<i>Oplostomus haroldi</i>	18(15.9)	25(22.1)	18.889	p<0.001
<i>Acherontia atropos</i>	2(1.8)	3(2.7)	0.056	0.814
<i>Galleria mellonella</i>	12(10.6)	19(16.8)	2.619	0.106
Termites	2(1.8)	2(1.8)	0.037	0.848
Black ants	8(7.1)	15(13.3)	0.004	0.947
Rats	9(8.0)	22(19.5)	13.894	p<0.001
Sugar ants	1(0.9)	1(0.9)	0.009	0.924

n = number, %= percent,

The mean difference in honey production in eight months compared using paired sample T-Test in SPSS (Table 5-4) was negative difference though not significant.

Table: 5-4 Mean difference in honey production in eight months

Description	Start	After	Mean difference	T- value	ρ – value
Mean production of honey (Kg)	1.78	1.6	-0.18	0.797	0.43

A chi square analysis showed that two factors that were significantly associated with honey production (number of pest species in a colony and the population size of a bee colony). High honey production was significantly associated with strong colonies of >15000 bees whereas small colonies of <500 bees were not associated with honey production. Honey production was not significantly associated with number of pests before but showed significant values after eight months. Low honey production was associated with co-occurrence of >3 pest species in one bee colony. A comparison between colony size and number of pests and pest combinations showed significant values after.

Table: 5-5 Relationship between honey production with colony size, number of pests and pest combinations

Comparison	Before		After	
	χ^2	P - value	χ^2	P - value
Honey productionVs colony size	38.3	0.000	43.0	p<0.001
Honey production Vs Number of pests	11.3	0.881	29.1	0.048
Honey production Vs pest combina- tions	16.0	0.596	35.0	0.069
Colony size Vs number of pests in a colony	30.0	0.186	42.8	0.011
Colony size Vs Pest combinations	29.0	0.225	53.2	0.011

Vs = comparison n = Number of honey bee colonies,

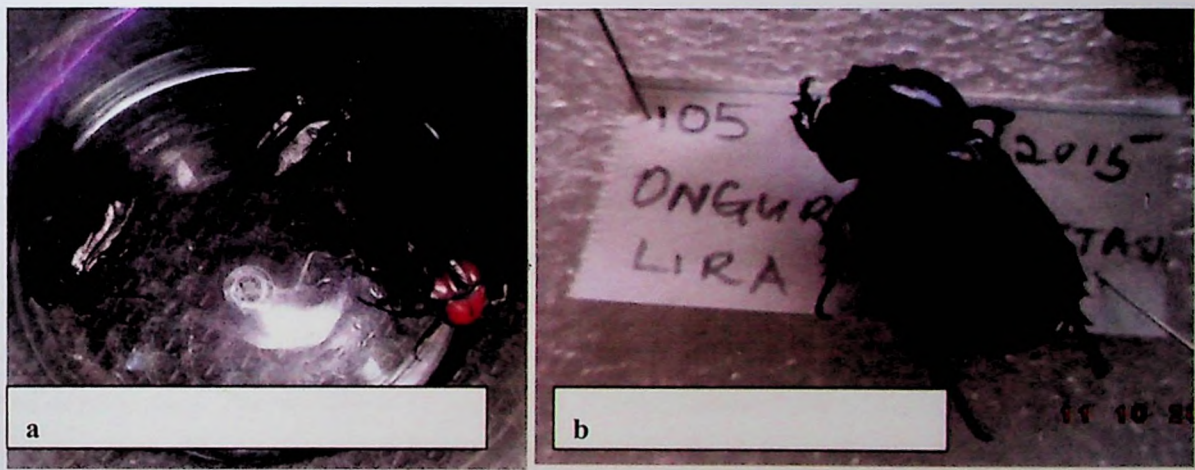


Plate: 5-2 a-Oplostomus haroldi, b-Oplostomus fulgineus

5.5 Discussion

Thirteen honey bee pests were recorded in this study. The parasitic honey bee mite, *Varroa* mites, three Coleopteran honey bee pests were present: Small hive beetle SHB (*Aethina tumida* spp) and two large hive beetles (LHB); *Oplostomus fulgineus* and *Oplostomus haroldi*, Lepidopteran species; the death head hawk moth *Acherontia Atropos* and the greater wax moth, *Galleria mellonella*. The Formicidae species found were Black ants, safari ants and sugar ants. Termites were found destroying bee hives in Nakasongola, Lira and Tororo. Small lizards (*Gecko sp*) often hid in empty spaces between the outer cover and top bars. Occasional pests in honey bee colonies included red frogs, pseudo scorpions and crickets.

These findings are in agreement with Wolfgang & Akwatanakul (2006), Kajobe et al. (2009), Fazier et al. (2010), Torto et al. (2010), Fombong et al. (2013), Kasangaki et al. (2016), and Chemurot et al. (2016). Wolfgang & Akwatanakul (2006) reported different pests worldwide that affect honey bee colonies which are beetles, ants, wax-moths, other Lepidoptera. Kasangaki et al. (2016) in Uganda, reported the presence of *Varroa* mites in all the districts and agro-ecological regions sampled. Our findings show *Varroa* and *Aethina tumida* as the most prevalent across all the studied districts. Kajobe et al. (2009) documented eleven pests and predators of honey bees in Uganda..

The presence of *O. haroldi* in honey bee colonies in two agro-ecological zones: Lake Victoria crescent and Mid Northern which are areas within Uganda's cattle corridor with herbivore dung, are in agreement with the findings of Fombong et al. (2012) who demonstrated under laboratory conditions that *O. haroldi* require decomposing plant material and herbivore dung for oviposition and development. The absence of *O. haroldi* in Western highlands agro-ecological zone which is a wetter area with commercial dairy farms where herbivore dung is abundant can be explained by ecological barriers. The presence of *O. haroldi* in Kenya's coastal areas and highlands was reported by Torto et al. (2010), Fombong et al. (2012), and Fombong et al. (2013).

The findings of this study have revealed that there was significant increase in number of honey bee colonies infested with *Oplostomus haroldi* and mice suggesting spread to bee colonies in the neighbouring agro-ecological zones. Fombong et al. (2013) reported that *O. haroldi* feeds on brood (both uncapped and capped), pollen and honey. This was evident in the field observations

where *O. haroldi* fed on honey, brood and its feeding habits destroyed combs. While Szabo and Lefkovitch (1989) reported a positive correlation between colony population size and brood production, its presence can result in reduced population size. It was also observed in this study that mice inhabiting active bee colonies built their nests on top bars and in the corners of a hive away from bee clusters. Their presence was tolerated by the bees and their urine and feces were not cleaned by bees and this could contaminate the honey. This calls for methods to eradicate the mice in honey bee colonies so as to avoid the contamination of hive products with their feces and urine.

This study's findings also suggest a small reduction in number of honey bee colonies infested with *Varroa* mites, small hive beetles and *Oplostomus fulgineus*, implying that African honey bees are capable to some extent to withstand some amount of pest infestations. This finding on *Varroa* reduction based on phoretic mites (mites on adult bees) in untreated colonies is in agreement with Strauss et al. (2014); in their studies in South Africa where the daily *Varroa* mite fall decreased over the experimental period in adult bees and brood of treated and untreated colonies. Strauss et al. (2014) also found that infestation rates of adult bees and brood of treated and untreated colonies was not significant and suggested that *Apis mellifera scutellata* had the ability to maintain low mite populations.

Field observations in this study showed that *Varroa* mites reproduced in both drone and worker brood but had a preference for drone brood (pers. observation). Similar observations in *Varroa* preference for drone brood were calculated to be 8.3 by Fuchs (1990) and 8.6 by Schulz (1984). Drone brood was rare to find, when present they were few scattered drone cells (pers. comm.). It's possible that workers of African honey bees are utilizing this preference ratio to reduce mite populations by removal of infested drone brood (hygienic behavior) and colony reduction in drone brood production. This observation agrees with Charrière et al. (2003) in their studies in Europe, in which they reported that the mite fall remained low in hives with cut out drone brood but rose rapidly in hives without removal of drone brood and the authors proposed removal of drone brood as an intervention to retard the progress of mite populations.

Dead beetles of *Oplostomus fulgineus* that were occasionally found covered in propolis at the bottom or hive walls (personal observation) could have resulted in the reduction of numbers of

infested colonies. It's possible that the beetles were killed by the bees then covered with propolis is in agreement with field observations by Donaldson (1989) in South Africa where he observed propolised dead beetles in bee hives.

Co-occurrence of pests and number of pest species in bee colonies were found to be significantly ($P < 0.05$) associated with honey production after eight months which means that the pest populations increased over time and their total negative impact on the honey bee colonies affected honey production negatively. This implies that a timely diagnosis of pests is needed for their effective control to achieve a healthy population of bees for honey production. The reduction in honey production could also be explained by the significant association between honey production and population sizes of a bee colony. High honey production was associated with strong colonies with populations > 15000 and low honey production associated with weak colonies < 2000 bees. These results are supported by the findings of Farrar (1937), Szabo and Lefkovitch (1989), Taha and Al-Kahtani (2013). In Egypt, Taha and Al-Kahtani (2013) found that colony population size was highly significantly associated with honey production in strong colonies than in weak colonies. In the United States of America, Farrar (1937) in his studies on influence of colony population on honey production reported that production efficiency of colonies increase as the population increases throughout the normal range of 15,000-60,000 bees.

5.6 Conclusion

Honey bees in Uganda are infested with a variety of pests. *Varroa* mites and *A. tumida* are common pests in honey bee colonies in Uganda. *Oplostomus haroldi* and *Acherontia atropos* are reported for the first time in Uganda's honey bee colonies in Nakasongola and Lira with an increasing number of colonies getting infested with *O. haroldi* suggesting more studies on the extent of spread. The observed honey production difference is attributed to co-infestation of pests and their increased populations over time impacting on the honey bee colony size. We suggest early detection and control of pests that reduce honey bee colony size by feeding on brood e.g. *O. haroldi* as a way to limit the impact of pests on honey production. Although the populations of *Varroa*, small hive beetles and *Oplostomus fulgineus* to some extent were controlled by the bees there is need to develop measures that will further reduce their populations in honey bee colonies.

CHAPTER SIX

VIRUSES CIRCULATING IN AFRICAN HONEY BEES IN UGANDA

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6.1 Abstract

The presence of *Varroa* mites in Uganda's bee colonies poses an assumption that the bee colonies could be harboring viruses vectored by *Varroa* mites as one of the possible causes of low honey production, a problem faced by Uganda's beekeepers. A study that aimed at identifying the bee viruses circulating in Uganda's bee colonies was conducted between April 2016 and May 2018 in two districts of Uganda; Lira and Kabarole. In this study pooled samples of adult worker bees from weak and strong colonies were screened for six honey bee viruses: Black Queen Cell Virus, BQCV; Acute Bee Paralysis Virus, ABPV; Sacbrood Virus, SBV; Chronic Bee Paralysis Virus, CBPV; Deformed Wing Virus, DWV and Kashmir bee virus, KBV using RT-PCR methods. Five out of the screened bee viruses BQCV, ABPV, SBV, CBPV and DWV were detected in Uganda's bee colonies; KBV was not detected. CBPV was the most frequently detected in the adult bee samples (20.4%), followed by BQCV (15.3%), then SBV (14.3%), ABPV (11.2%) and DWV (1.0%). Two apiaries (Ngetta 1 and Kyenjojo) did not test positive for any of the screened six bee viruses. Occurrence of more than one virus in a single apiary or in a bee colony was observed. CBPV presence was significantly ($p = 0.0074$, at 95% confidence interval: 1.3 to 21.3) affected by correlated with colony strength. The proportion of infected colonies scored as strong for CBPV was less than that of weak infected colonies. Presence of the other four viruses detected in the honey bee colonies (BQCV, ABPV, SBV and DWV) were all not significantly affected by colony strength. The detection of bee viruses in different agro-ecological zones of Uganda suggests their spread in the country. These findings make it necessary for a time series follow up of infected colonies to evaluate colony survival after longer periods of infection.

Key words: honey bee viruses, honey production, Uganda

6.2 Introduction

Worldwide, honey bees are hosts of more than 20 identified bee viruses (de Miranda et al., 2011); most of them are single stranded RNA viruses belonging to Order Picornavirales; which has five families, two of which (Iflaviridae and Dicistroviridae) contain the common bee viruses (De Smet et al., 2012). Nine of these bee viruses on the African continent are reviewed by Pirk et al. (2016): the Acute Bee Paralysis Virus (ABPV), Israeli Acute Paralysis Virus (IAPV), Black Queen Cell Virus (BQCV) were reported in South Africa (Strauss et al., 2013). In Kenya, Muli et al. (2014a) detected ABPV, BQCV and Deformed Wing Virus (DWV). In Benin Amakpe et al., (2015) reported Lake Sinai Virus (LSV), while Onyango et al. (2016) added to Kenya's bee viruses the *Varroa destructor* Virus-1 (VDV-1) and Kakugo Virus. *Apis mellifera* filamentous virus (AmFV) in South Africa is reviewed by Allen & Ball (1996). In Uganda Kajobe et al. (2010a) detected the BQCV and none of the samples screened in their study tested positive for Chronic Bee Paralysis Virus (CBPV), Sac Brood Virus (SBV), ABPV, DWV, IABP, nor *Apis* iridescent virus, AIV. Studies of Chemurot, (2017) show presence of ABPV, SBV, DWV, LSV and BQCV in bee colonies in eastern and western agro-ecological zones of Uganda.

The viruses persist as covert asymptomatic infections but their levels increase in stressful conditions causing reduced colony growth, foraging, resource availability, worker longevity and brood survival (Mingxiao et al., 2013; Degrandi-hoffman & Chen, 2015). Most of these viruses have been detected in *Varroa* mites and are transmitted through parasitism (Gisder et al., 2009; Genersch & Aubert, 2010; De Miranda et al., 2013; Degrandi-hoffman & Chen, 2015). By feeding on the haemolymph of bee brood and adult bees, *Varroa* mites suppress the bees' immune system (Rosenkranz, Aumeier et al., 2010; Degrandi-hoffman & Chen, 2015). These viruses infect all the developmental stages and castes of honey bees (Degrandi-hoffman & Chen, 2015). Single and multiple virus infections in honey bees was detected by Chen et al. (2004), in USA and in Kenya by Muli et al. (2014a).

The presence of *Varroa* mites is reported on the African continent (Fazier et al., 2010; Kasangaki et al., 2016). Fazier et al. (2010) reported *Varroa* mite presence in Kenya, whereas Kasangaki et al. (2016) reported in Uganda's bee colonies. When BQCV was detected by Kajobe et al. (2010), *Varroa* mites had not been reported in the Uganda's bee colonies and serious consequences

were expected with BQCV disease after the detection of *Varroa* mites in the districts endemic with BQCV (Kajobe et al., 2010). With the presence of *Varroa* mites in Uganda's bee colonies, there was an assumption of existing colonies harboring other bee viruses that could be impacting on the country's honey production through reduced colony growth, foraging and resource availability. This study was designed with the objective of identifying the bee viruses circulating in Uganda's bee colonies and their effect on colony strength.

6.3 Materials and methods

6.3.1 Study location

Honey bee colonies were sampled from seven apiaries in two districts representing two agro-ecological zones of Uganda; Kabarole (00°36'N, 30°18'E) and Lira (2°20'N, 33°06') Kabarole represents the Western highlands, while Lira represents the Mid North . These districts were selected purposefully for intensive bee keeping in their AEZ.

6.3.2 Sample collection and storage

Samples of adult worker honey bees were collected in plastic jars from the brood nest of honey bee colonies that were weak and those that apparently looked healthy (Table 6-1). The collected samples were then transferred into cryo-vials filled with RNA-Later while still in the field to stabilize the RNA and stored at -20° C on arrival at the laboratory until analyzed. A total of 98 samples of adult bees were collected from the seven apiaries. 97 of these samples were taken from 10% of honey bee colonies randomly sampled from six apiaries, while one sample (nd) was a collective sample pooled from 10 honey bee colonies of one apiary 'nd' made for the PCR analysis. A sample consisted of ten adult worker bees. All the sampled colonies had *Varroa* mites. The samples were collected in October and November 2017.

Table: 6-1 Apiary sites and number of bee samples taken from Mid North and Western highlands agro-ecological zones

Agro-ecological Zone	Apiary code	Colony strength	
		Weak (<2000 bees)	Strong (>10,000 bees)
Mid North	Amach 1 (n=15)	2	13
	Amach 2 (n=21)	1	20
	Ngetta 1 (n=13)	0	13
	Ngetta 2 (n=18)	1	17
Western highlands	Kyenjojo (n=10)	4	6
	Rwebitaba (n=20)	6	14
	nd (n=10)	1	9

Numbers represent-number of samples from weak /strong colonies drawn from the apiary; <2000 bees and >10,000 bees are parameters used to rate weak and strong colonies respectively

6.3.3 Pathogen diagnosis

Each sample was screened for six bee viruses using RT-PCR methods: Acute Bee Paralysis Virus (ABPV), Black Queen Cell Virus (BQCV), Deformed Wing Virus (DWV), Sacbrood Virus, (SBV), Chronic Bee Paralysis Virus (CBPV) and Kashmir Bee Virus (KBV). The laboratory analyses described were performed at the Gulu University Bioscience Laboratory.

6.3.4 RNA extraction

Total RNA from the pooled samples¹ was extracted using TRIzol[®] LS Reagent following the manufacturer’s protocol. Ten worker bees pooled per honey bee colony and 45 *Varroa* mites (phoretic on adult bees and in brood) pooled per apiary were crushed in liquid nitrogen using a sterilized glass-Teflon and homogenized in TRIzol[®] LS Reagent. Total RNA was extracted from the samples using TRIzol[®] LS Reagent following manufacturer’s protocol. After homogenizing the sample with TRIzol[®] LS Reagent, Chloroform was added and the homogenate allowed to separate into a clear upper aqueous layer containing RNA and inter-phase and red lower organic layer containing DNA and proteins. The total RNA was then precipitated from the aqueous layer using 100% Isopropanol. There after the precipitated RNA was washed in 75% ethanol to re-

¹ A pooled sample consisted of 10 bees taken from a single honey beehoney bee colony.

move impurities and re-suspended in Ribo-nuclease free water/distilled water. The sample (RNA) was then used for the downstream molecular reactions.

6.3.5 Complementary DNA/cDNA synthesis

Complementary DNA (cDNA) synthesis was performed using M-MuLV reverse transcriptase. All reaction steps were performed in a thermo cycler with a heated lid (100⁰C) using PCR tubes. 2µl of the total extracted RNA and 1µl of reverse primer was added to a tube containing a 17 µl master mix (5 µl of M-MuLV reverse transcriptase buffer, 4 µl of 200 µM dNTP mix, 1 µl of 10mg/µl BSA, 1 µl of 1U R-Nase Inhibitor, 5.5 µl of PCR water and 0.5µl of 100U M-MuLV reverse transcriptase) in a final reaction volume of 20 µl for each sample. The samples were then incubated at 22⁰ for 10 minutes, 42⁰ C for 40 minutes, then 95⁰ C for 4 minutes to inactivate the enzyme.

6.3.6 PCR amplification

For PCR amplification reaction, 2µl cDNA template and 1µl of 10 µM of each forward and reverse primer was added to 21µl of a master mix containing 5µl of 1X Taq reaction buffer, 4µl of 200 µM of dNTP mix, 7µl of 2 mM of MgCl₂, 4.875µl PCR water and 0.125µl of 1.25U Taq DNA polymerase in a reaction volume of 25µl. The PCR was run at 94⁰ C for 5 minutes, (94⁰ C for 30 seconds, 50⁰ C for 30 seconds, 72⁰ C for 1 minute) for 35 cycles with a final extension step of 1 cycle at 72⁰ C for 10 minutes.

Table: 6-2 Primers used for screening BQCV, ABPV, KBV, DWV, SBV and CBPV

Virus name	Primer name	Amplification target	Sequence (5'-3')	Length bp	Reference
BQCV	BQCV-F	Structural poly-protein gene	TGGTCAGCTCCCACTACCTTAAAC	700	Benjeddou et al. (2001)
	BQCV-R		GCAACAAGAAGAAACGTAAACCAC		Benjeddou et al. (2001)
ABPV	ABPV-F	RNA polymerase gene	TTATGTGTCCAGAGACTGTATCCA	150	Benjeddou et al. (2001)
	ABPV-R		GCTCCTATTGCTCGGTTTTT		Benjeddou et al.

Virus name	Primer name	Amplification target	Sequence (5'-3')	Length h bp	Reference
	R		CGGT		(2001)
KBV	KBV-F	RNA polymerase gene	GATGAACGTCGACCTATTGAA	393	Stoltz et al. (1995)
	KBV-R		TGTGGGTTGGCTATGAGTTCA		Stoltz et al. (1995)
DWV	DWV-F	Gene for poly-protein	TTTGCAAGATGCTGTATGTGG	395	Tentcheva et al., (2006)
	DWV-R		GTCGTGCAGCTCGATAGGAT		Tentcheva et al., (2006)
SBV	SBV-F	Poly-protein gene	GGATGAAAGGAAATTACCAG	426	Tentcheva et al. (2004)
	SBV-R		CCACTAGGTGATCCACACT		Tentcheva et al. (2004)
CBPV	CBPV-F	Viral capsid gene	AGTTGTCATGGTAACAGGATACGAG	900	Rivière et al. (2002)
	CBPV-R		TCTAATCTTAGCACGAAAGCCGAG		Rivière et al. (2002)

PCR Analyses: The PCR reaction amplification products were analysed by electrophoresis on 1.5% high resolution agarose gel stained with 3µl ethidium bromide and visualized under UV light.

Primer design: The reverse and forward PCR primers used for screening BQCV; ABPV; KBV; DWV; SBV and CBPV (Table 6-2) were according to Antúnez et al. (2006). All the primers were supplied by Inqaba biotec East Africa Limited.

Data analysis: Each detected virus was analysed individually using Fisher's exact test of independence of the fife Package (Fife, 2014) in R. The analysis was conducted using the program (R Core Team., 2014) to test whether the proportions of number of viruses detected are heteroge-

neous with the honeybee colony strength. A pairwise Fisher's test followed by Bonferroni pairwise correction was implemented to identify the significant pairwise comparisons.

6.4 Results

Five honey bee viruses (BQCV, ABPV, SBV, CBPV, and DWV Table 6-3) were detected in 35.7% of the samples tested. KBV was not detected while samples taken from two apiaries (Ngetta I and Kyenjojo) did not test positive for any of the screened six bee viruses. Two viruses CBPV and BQCV were detected from samples from Western highlands agro-ecological zone, while all the five viruses detected in this study came from samples of Mid North agro-ecological zone.

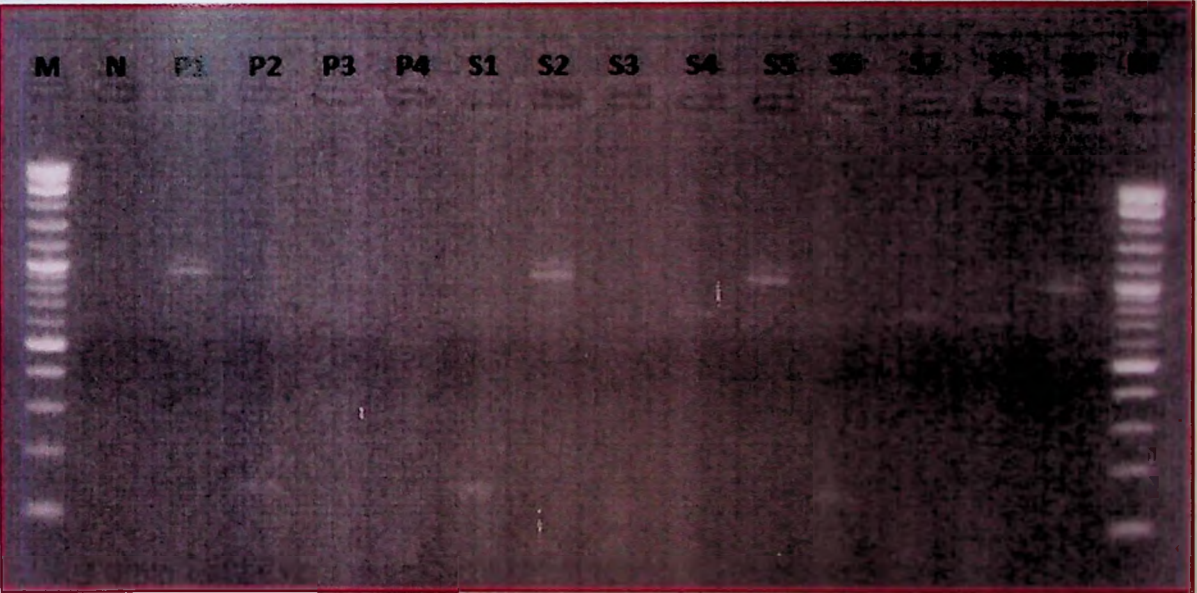


Plate: 6-1, RT-PCR analysis for six bee viruses

BQCV; ABPV; KBV; DWV; SBV and CBPV in honey bees *Apis mellifera* collected from symptomatic and asymptomatic colonies. M is the 100 bp DNA molecular ladder, lane N, is water for negative control, lane P1 is positive for CBPV, lane P2 is positive for ABPV, lane P3 is positive for BQCV and lane P4 is positive for SBV. Lanes S1 and S6 were positive samples of ABPV; Lanes S2, S5 and S9 were samples positive for CBPV; Lane S3 was a sample positive for SBV; Lane S4, S7 and S8 were samples positive for BQCV.

Table: 6-3 Bee viruses in apiaries in Mid North and Western highlands agro-ecological zones of Uganda. Samples collected from October to November 2017

Location		Honey bee Viruses					
AEZ	Apiary Code	CBPV	BQCV	KBV	DWV	SBV	ABPV
Mid North	Amach 1	+	+	-	-	+	+
	Amach 2	+	+	-	+	+	+
	Ngetta 1	-	-	-	-	-	-
	Ngetta 2	+	+	-	-	+	+
Western high-lands	Kyenjojo	-	-	-	-	-	-
	Rwebitaba	+	+	-	-	-	-
	nd	+	-	-	-	-	-

+: presence; -: absence

CBPV was the most frequently detected in the adult bee samples (20.4%), followed by BQCV (15.3%), then SBV (14.3%), ABPV (11.2%) and DWV (1.0%) (Table 6-4). Occurrence of more than one virus in a single apiary or in a bee colony (Table 6-5) was detected in samples from four apiaries. None of the six bee viruses (ABPV, BQCV, SBV, KBV, CBPV, ABPV) screened was detected in the *Varroa* mite samples.

Table: 6-4 Relative abundance of honey bee viruses in apiaries of Mid North and Western highlands agro-ecological zones of Uganda. Samples taken from October to November 2017

Honey bee	Location/origin						
	Mid North AEZ				Western highlandsAEZ		
Virus	Amach 1(n=15)	Amach 2(n=21)	Ngetta 1(n=13)	Ngetta 2(n=18)	Kyenjojo(n=10)	Rwebitaba(n=20)	Total (98)
CBPV	5	4	0	1	0	10	20(20.4)
ABPV	6	4	0	1	0	0	11(11.2)
SBV	4	9	0	1	0	0	14(14.3)
DWV	0	1	0	0	0	0	1(1.0)
BQCV	5	6	0	1	0	3	15(15.3)
KBV	0	0	0	0	0	0	0(0)

Numbers represent number of infested colonies. Numbers in bracket in total the column represent the percentage of infected colonies

Another aspect that was investigated was virus presence and colony strength. CBPV presence was significantly ($p = 0.0074$, at 95% confidence interval: 1.4 to 21.4) was correlated with colony strength. The proportion of infected colonies with CBPV scored as strong was less than that of weak infected colonies.

Presence of the other viruses detected in the honey bee colonies; ABPV ($p = 0.655$, at 95% confidence interval: 0.1303 to 7.9770), SBV ($p = 0.2095$, at 95 percent confidence interval: 0.0 to 1.7) and DWV ($p = 1.0000$, 95% confidence interval: 0.0 to 233.1) were all not correlated with colony strength. The total number of viruses detected was not significantly ($p = 0.1839$) correlated with the colony strength.

Table: 6-5 Co-occurrence of viruses in honey bee colonies in Mid North and Western highlands agro-ecological zones

No of virus-es	Type of infection	Location/Origin					
		Mid North AEZ				Western highlandsAEZ	
		Amach 1 n=15	Amach 2 n=21	Ngetta 1 n=13	Ngetta 2 n=18	Kyenjojo n=10	Rwebitaba n=20
1	CBPV	-	-	-	-	-	8
	ABPV	1	-	-	-	-	-
	SBV	1	4	-	-	-	-
	DWV	-	-	-	1	-	-
	BQCV	2	1	-	-	-	1
2	CBPV- ABPV	1	-	-	-	-	-
	ABPV- SBV	-	1	-	-	-	-
	SBV- BQCV	-	1	-	-	-	-
	CBPV- BQCV	-	-	-	-	-	3
3	CBPV-ABPV-SBV	1	-	-	-	-	-
	CBPV-ABPV-BQCV	1	1	-	-	-	-
	CBPV-SBV-BQCV	-	1	-	-	-	-
4	CBPV-ABPV-SBV-BQCV	2	2	-	1	-	-

nd all samples from this apiary were pooled to make one sample. Numbers represent number of infested colonies

6.5 Discussion

In this study, five different bee viruses; BQCV, ABPV, SBV, CBPV and DWV with CBPV as a new virus detected in Uganda's bee colonies. This report on the presence of bee viruses in Uganda follows reports by Chemurot (2017) and Kajobe et al. (2010). In their study, Kajobe et al. (2010) detected only BQCV from the Uganda's bee colonies and none of their samples tested positive for DWV, SBV, ABPV, CBPV. The findings of Kajobe et al. (2010) show that BQCV was more prevalent (40%) in Western-highlands agro-ecological zone with a single positive sample from the Mid North agro-ecological zone.

The study of Chemurot (2017) in Eastern and Western highlands agro-ecological zone reported the presence of DWV, ABPV, BQCV and SBV in Uganda's honey bee colonies. In his study, Chemurot (2017) did not detect CBPV, but found BQCV, DWV, ABPV and SBV in samples from the two zones, with DWV as the most prevalent. In the present study, all the five different bee viruses (BQCV, ABPV, SBV, CBPV and DWV) were present in the Mid North agro-ecological zone whereas only two CBPV and BQCV were detected in samples from Western highlands AEZ.

The presence of CBPV which was not detected before in the study of Chemurot (2017) and Kajobe et al., (2010) suggests recent invasion in Western highlands and Mid North agro-ecological zones. The possible explanation for CBPV not being detected before in Uganda and its neighbors is that; CBPV onset of symptoms can be sudden and the outbreak location unpredictable as described by (Budge, 2017). Its occurrence could not have been influenced by season; sample collection of the present study and the study of Chemurot (2017) in Western-highlands, was in the second wet season.

The high prevalence of CBPV (20.4%) in this study shows that its prevalence could be increasing as described by Traynor et al. (2016) in their study USA where CBPV presence doubled annually from 2010 when it was first detected in 0.7% of the colonies. According to Budge (2017) the disease is not commonly detected when random apiaries are tested, the prevalence is higher when apiaries with poor health are targeted. The implication of this that the prevalence would have been higher in the present study if apiaries with poor health were targeted.

In this study CBPV presence significantly correlated with colony strength, with infected colonies less in strong than weak infected colonies suggests its presence weakening colonies. This finding is supported by the (Ribi re, Olivier, & Blanchard, 2010) who state that the disease affects strong colonies and thousands are seen dead in front of hives making it a risk factor for colony weakness. In our study symptoms of the disease as described by (Ribi re, Olivier, & Blanchard, 2010) were not observed in apiaries. Similar findings were reported by (Ant nez et al., 2006) in Uruguay where infected colonies that did not show any symptoms eventually died after the study. The implications of this to our study is that colony strength may continue to decline due to CBPV.

The possible explanation of the absence of DWV, ABPV, and SBV in samples obtained from Western highlands as compared to the findings of Chemurot (2017) is that some apiaries are still free of viruses. The present study and that of Chemurot (2017) in Western highlands agro-ecological zone sample collection was done in different apiaries. The implication of this is that spread of these viruses should be controlled.

The finding that shows the presence of the other viruses (BQCV, ABPV, SBV, DWV) detected in the honey bee colonies not significantly affected by the colony strength is related to findings of Onyango et al. (2016) who found no association between presence of viruses colony strength. The implications to this are that the invasion of Uganda's honey bee colonies by different bee viruses requires time to monitor infected colonies to ascertain the impact of the disease.

6.6 Conclusion

Here we report one new honey bee virus CBPV that has recently invaded the Uganda's bee colonies in addition to the DWV, SBV, ABPV, and BQCV. We also report multiple bee virus infections in some colonies. CBPV is impacting negatively on colony strength thus affecting honey production. Its high prevalence shows infected colonies increasing thus the colony strength of more honey bee colonies may continue to decline due to CBPV, suggesting monitoring, early detection of CBPV in honey bee colonies & formulation of control methods. The presence of other viruses did not affect colony strength.

CHAPTER SEVEN

IMPORTANT PLANTS FOR HONEY PRODUCTION IN DIFFERENT AGRO-ECOLOGICAL ZONES OF UGANDA

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7.1 Abstract

Plants are important floral resources for honey bees. The role of collecting pollen and nectar from flowers is done by worker bees. The pollen is stored as bee bread, while the nectar is converted to honey and stored in different cells. Lack of consolidated data on bee forage is a limitation in honey production. This led to a study that identified bee forages in four out of ten agro-ecological zones (AEZ) of Uganda (between May-2014 and May-2016). Plants with flowers within the experimental plots were observed for the presence of foraging honey bees, while honey production records per hive were obtained from beekeepers. 75 bee forage belonging to 31 plant families were recorded. The most visited was Family Fabaceae; which contributed 21% of the foraged plant species, followed by the Family Asteraceae 11.8% and Family Lamiaceae 7%. In Lake Victoria crescent AEZ, the dominant bee forages were: *Combretum spp.*, *Albizia spp.*, *Piliostigma thonningii*, *Vitex doniana*, *Harrisonia abyssinica*, and *Acacia polyantha*. In Mid North, the dominant species were cultivated crops (*Sesamum indica*, *Helianthus annuus*, *Cajanus cajan*) and indigenous plants *Guizotia scabra*, *Ocimum tenuiflorum*, *Stachytarpheta jamaicensis* and *Urena lobata*. While in Kyoga plains, the dominant species were 2 cultivated crops (*Manihot esculenta* and *Zea mays*) (seasonal flowering crops) and weeds *Bidens pilosa*. However the western highland sites, *Musa paradoxica* was the dominant species. AEZs significantly ($df = 3$, $F = 60.5$, $P < 0.001$) influenced and accounted for 95.32% of the observed variations in bee forage species cover. Apiary location also significantly ($df=13$, $F=1.9$, $P < 0.05$) influenced the different honey bee forage species recorded, however it only accounted by a dismal 3.05% leaving a small residual contribution of 1.63%. A two way ANOVA subjected to honey production data revealed, apiary location significantly ($df=13$, $F=4.5$, $P < 0.001$) contributing to the observed vari-

ations in average honey harvested accounting for 57.74% of the observed variation. The ANOVA result also showed significant ($df=13$, $F=4.5$, $P<0.001$) differences in honey production for sites within and between different AEZs. The dominant species in a location have an influence on honey production and the observed honey production differences per hive in sites of AEZs with similar bee forage cover is attributed to other apiary factors.

Key words: honey, honey bee forage plants, honey production

7.2 Introduction

The diet of honey bees consists of protein rich pollen and sugar rich nectar collected separately or synchronously from flowers by foraging worker bees (Kajobe, 2006, 2007). These resources are collected in quantities that exceed colony demands and are stored for dearth periods; The nectar is converted into honey and pollen stored as bee bread (Nicolson, 2011; Anderson et al., 2014). While collecting nectar and pollen, bees deposit pollen from anthers to the stigma resulting in pollination and increased fruit set (Vidal et al., 2010). In the U.S.A., Morse & Calderone (2000) estimated the value of crop production achieved through pollination by honey bees alone at \$14.6 billion. The value of honey production by bees in Africa is 159,801 tones.

Some plants have been observed to be heavily visited by the honey bees while others are less frequently visited (Bendifallah et al., 2013; Couvillon et al., 2015). Nectar and pollen resource depletion induced by prolonged wet seasons or overheating in the dry seasons is known to cause migration or absconding in honey bees (Winston et al., 1978; Hepburn, 2006). According to Larinde et al. (2014a), the production of honey is dependent on the quality and quantity of floral sources at their disposal. Studies by Beyene et al. (2015) in Ethiopia also showed that location and hive type interaction has significant effect on honey production per hive. According to a study by Abdullahi et al. (2011) in Nigeria, bee forage plants are not always evenly distributed.

Uganda has a high potential for honey production but have not yet exploited. Bee forage in Uganda have been studied by Katende et al. (1995), Kajobe (2006), Kajobe et al. (2009) and Kangave (2015). Kajobe (2006) lists heavily visited bee forage of *Apis mellifera* and stingless bees in Bwindi Impenetrable National Park in south western Uganda; (*Bidens pilosa*, *Carapa grandifolia*, *Croton macrostychus*, *Entandrophragma excelsum*, *Markhamia lutea*, *Prunus afri-*

cana, *Syzigium guinense*, *Vernonia sp.*). Kangave (2015) lists 46 bee forage in selected agro-ecological zones of Uganda. Kajobe et al. (2009) listed plants used by the bees in Western highlands and Eastern AEZs. These authors don't relate the dominant bee forage in the studied zones with honey production.

The current production of honey in Uganda is estimated at only 8000-9000 metric tones (MAAIF/UBOS, 2010; Uepb, 2005). Honey production in Uganda varies from one agro-ecological zone to another and within a zone. Northern Uganda records 640 Metric Tones of honey annually while central region has the least 85 Metric Tones (MAAIF/UBOS, 2010; Kilimo Trust, 2012).

Identifying honey bee floral sources specific to a region is essential in honey production and selection for suitable apiary sites as beekeepers can use this information to selectively grow plants that are important to the bees (Kajobe, 2006; Abou-Shaara, 2015). The aim of this study was to identify bee forages used in honey production by honey bees, *Apis mellifera* in four of ten agro-ecological zones of Uganda. Three variables were evaluated for influencing honey production; 1) preferred pollen and nectar sources 2) the diversity of preferred plant species by the bees 3) the relationship between honey production per hive and bee forage species dominance cover with AEZ and site.

7.3 Materials and Methods

7.3.1 Study sites

The study sites are located in four agro-ecological zones of Uganda; Mid North agro-ecological zone (AEZ), the Lake Victoria crescent AEZ, the Western highlands AEZ and Kyoga plains AEZ (UNBS, 2017a, 2017c, 2017d, 2017e). The four AEZs were selected basing on the differences in vegetation cover, honey production quantities and number of beekeepers (MAAIF/UBOS, 2010). The four study sites/apiaries in each AEZ were selected with the help of the respective beekeeping extension workers making a total of 16 apiary/study sites. In each zone at least one apiary was located in natural vegetation while others were in farming areas.

7.3.2 Research design

Both quantitative and qualitative data were collected. Quantitative data included bee plant species and their abundance. Qualitative data was based on observation of rewards to pollinators, Nectar N, Pollen P, Pollen and Nectar P+N and classification of plants in relation to foraging intensity.

7.3.3 Data collection (observation of bees foraging at flowers)

Experimental plots measuring 1000 x 1000 meters were set up around each study apiary. On each study visit, each experimental plot was divided into 9 blocks measuring 333 x 333 meters and observation made on 4 blocks selected randomly. A total of 16 experimental plots were used, four located in each AEZ. Plants seen with flowers within the experimental plots were observed for the presence of foraging honey bees. The target populations were plants: shrubs, trees, agricultural crops, weeds, pastures. A plant species was scored as a bee forage when at least 3 bees were seen collecting either pollen or nectar within 10 minutes. A plant recorded as bee forage at one block when encountered in subsequent blocks was recorded for presence and dominance cover. The observations in each site were repeated monthly to ensure that all the bee forage was captured. Observations were done during time of peak foraging activity between 9:00-12:00 hours. The foraging behavior of bees at flowers was observed to ascertain that the bees were collecting either nectar or pollen; when seen running fast over anthers, removing pollen from their hairy bodies and placing on the pollen basket (this was recorded as pollen foraging) and nectar collection was recorded when the bees delved down deep into flowers, or when seen sucking nectar from the outside through corolla tube of tiny flowers with long corollas. Bees foraging on tall trees were observed using a pair of binoculars. The flowering period of each bee forage species was determined through continuous monitoring and recording of flowering patterns including commencement and end of flowering period. Species with multiple flowering seasons were also recorded. This was adapted from methods used by (Abdullahi et al., 2011; Adgaba et al., 2017).

7.3.4 Collection and preparation of specimens for identification

The samples were collected, pressed as described by Lacey, Short & Mosley (2001) and identified by a qualified taxonomist at the Makerere University Herbarium. The voucher deposited at the same Herbarium.

7.3.5 Data analysis

All the data was analysed in R-studio, Pie charts of dominant plant species by family was generated from the data on bee forages. The data of land cover by bee forage plants was subjected to a two way ANOVA, having detected a large variation in plant species dominance cover contributed by AEZ, the ANOVA results were then subjected to TukeyHSD multiple range test to identify which AEZs were actually different from each other. The honey production data was also subjected to a two way ANOVA, when the site (apiary) location contributed to the observed variation in average honey harvested. The validity of the ANOVA analysis on honey production was assessed graphically using Residuals against fitted values and standardized residuals against theoretical quantiles and found to be within the acceptable model variation. A pair wise comparison of average honey production per hive between different sites was done using TukeyHSD multiple range test.

The AEZ and Apiary site were the independent variables while the plant species score and honey production per hive were the dependent variables used in the ANOVA analysis.

7.4 Results

7.4.1 Bee forage species identified

A total of 75 plant species belonging to 31 plant families were foraged upon by the honey bees during the wet and dry seasons in the study sites. The most visited Family of plants was Fabaceae; which contributed 21% of the foraged plant species, followed by the Family Asteraceae 12% and Family Lamiaceae 7% (Figure 7-1). The bees collected either nectar or pollen or both pollen and nectar from the flowers. The highest number of bee forage species $n=62$ occurred at two sites in Nakasongola district (Kazwama and Nakasongola Apiculture Centre)

while the least number of species $n=20$ occurred in the Kabarole district (Nsura 2). This shows that all the study sites had a considerable number of bee forage floral species.

The results of top 10 dominant species foraged on by the honey bees in the different AEZ (Figure 7-2 to 7-3) revealed that; in Lake Victoria crescent, the dominant species foraged by the bee were indigenous (wild) plants: *Combretum molle*, *C. collum*, *Albizia* spp, *Piliostigma thonningii*, *Vitex doniana*, *Harrisonia abyssinica*, *Guizotia scabra*, *Ocimum tenuiflorum*, and *Acacia polycantha*. In Mid North the dominant species were cultivated crops (*Sesamum indica*, *Manihot esculenta*, *Helianthus annus*, *Cajanus cajan*) and indigenous (wild) plants *Guizotia scabra*, *Ocimum tenuiflorum*, *Vitex doniana*, *Combretum* spp, *Stachytarpheta jamaicensis*, *Triumfetta cordifolia*, *Urena lobata*, *Vernonia* spp.

In Kyoga plains the dominant species were two cultivated crops (*Manihot esculenta* and *Zea mays*) and weeds *Bidens pilosa* dominant in 2 sites While in all Kabarole sites *Musa paradoxica* was the dominant species and was cultivated at all sites.

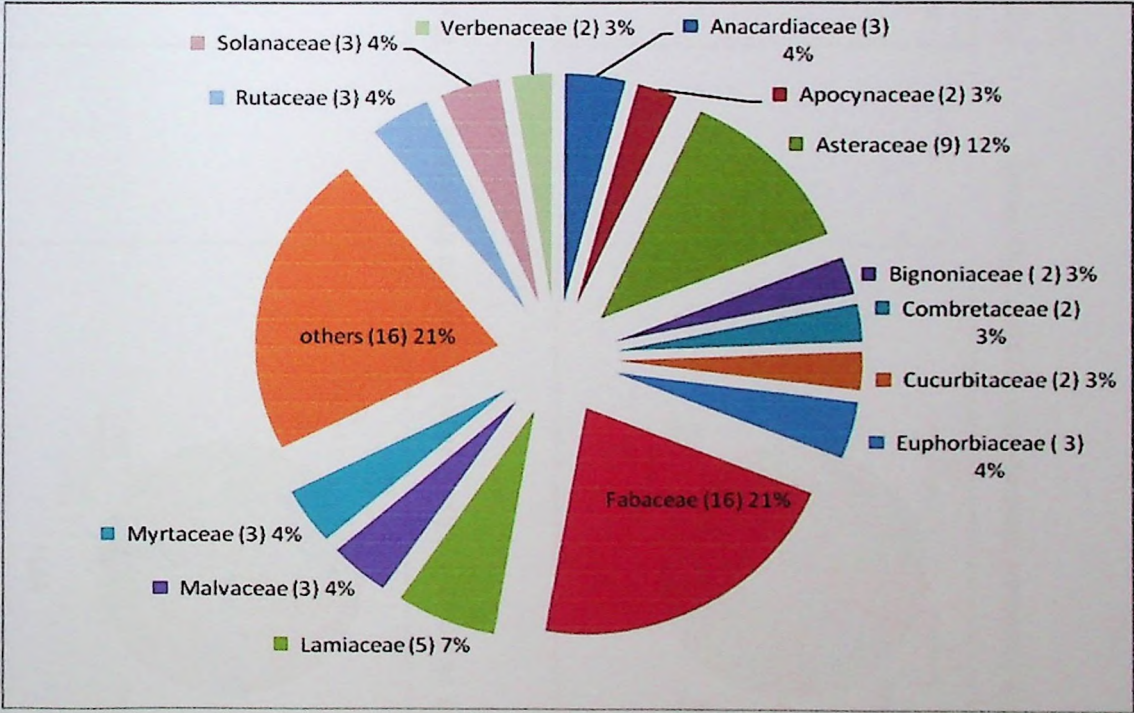


Figure 7-1 A summary of plant species per family recorded in 4 AEZs between April 2015-April 2016. The group named others represents 16 plant families, each family represented by one plant species

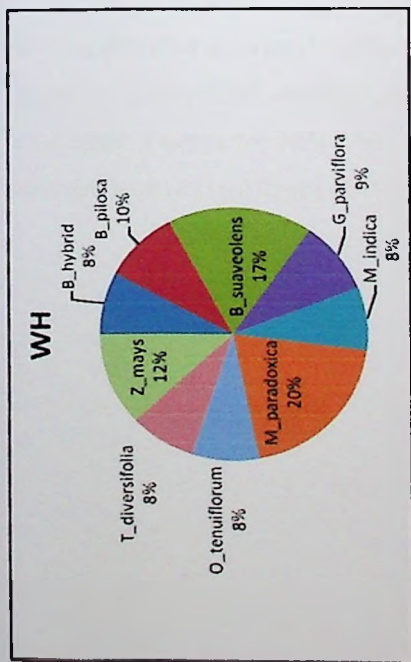


Figure 7-2 Top 10 dominant bee forages in Western highlands
cent

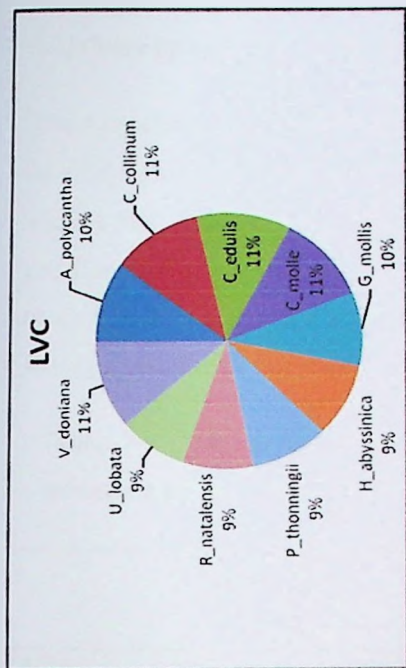


Figure 7-3 Dominant bee forages in Lake Victoria Cres-

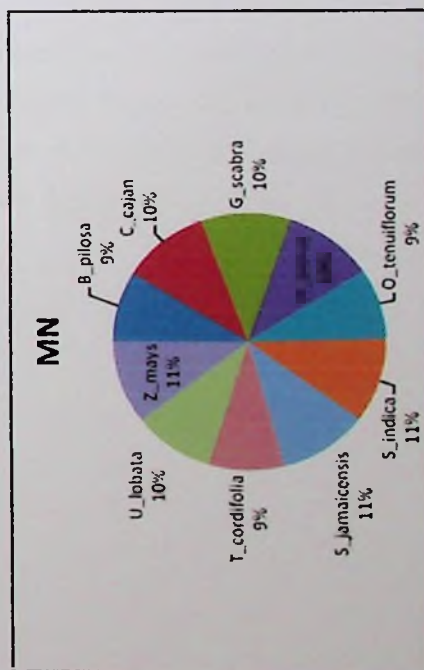


Figure 7-4 Top 10 dominant plant species foraged Mid North

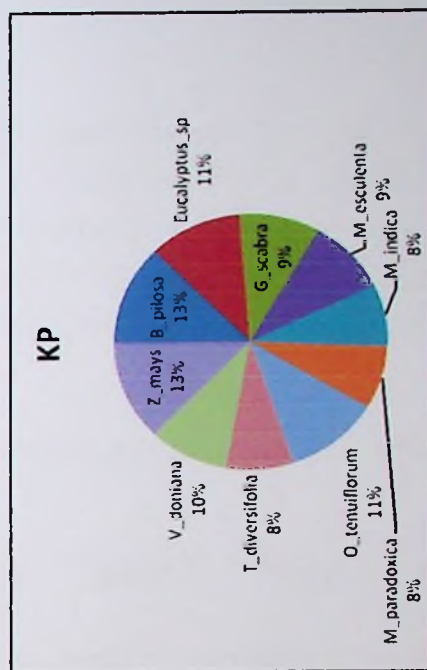


Figure 7-5 Top 10 dominant plant species foraged in
Kyoga plains

7.4.2 Cover of bee plant forage species

After subjecting the data of land cover by bee forage plants to a two way ANOVA, it is clear that the AEZ significantly ($df = 3, F = 60.5, P<0.001$) influenced the honey bee forage species cover in areas that were sampled (Table 7-1). The AEZ accounted for 95.3% of the observed variation. The site (apiary) location also significantly ($df=13, F=1.9, P<0.05$) influenced the different honey bee forage species recorded (Table 7-1). However it only accounted by a dismal 3.05% leaving a small residual contribution of 1.6%.

Table: 7-1 Comparison between species dominance score with AEZ, site and interaction between AEZ and site

comparison	df	Sum Sq	Mean Sq	F value	Pr(>F)
AEZ	3	120.9	40.3	60.5	<2e-16 ***
Site	13	16.8	1.3	1.9	0.0224 *
Residuals	1258	837.5	0.7		

Values with codes: '****' and '*' were significant

Having detected a large (95.3%) of variation contributed by AEZ, the ANOVA results were subjected to TukeyHSD multiple range test to identify which AEZs were actually different from each other. Except for MN-LVC ($P>0.05$) all the other pair wise comparisons between the AEZs returned highly significant ($P<0.001$) differences summarized in Table 7-2.

Table: 7-2 Comparison between bee forage plant species dominance scores for different Agro-ecological zones

comparison	estimate	conf.low	conf.high	adj.p.value
LVC-KP	0.45	0.29	0.63	6.67 e-11
MN-KP	0.48	0.31	0.65	4.23 e-12
MN-LVC	0.03	-0.14	0.19	0.98
WH-KP	-0.22	-0.39	-0.06	2.22 e-03
WH-LVC	-0.68	-0.84	-0.52	5.45 e-14
WH-MN	-0.71	-0.87	-0.53	3.3e-14

WH-Western highlands, MN- Mid North , LVC-Lake Victoria Crescent and KP=Kyoga Plains

7.4.3 Honey production per hive

When the honey production data was subjected to a two way ANOVA, the site (apiary) location significantly (df=13, F=4.5, P<0.001) contributed to the observed variation in average honey harvested (Table 7-3). Differences due to site (apiary) location accounted for 57.7% of the observed variation in honey harvests.

Table: 7-3 Comparison between average honey production per hive with AEZ, site and interaction between AEZ and site

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
AEZ	3	1.2	0.4	2.3	0.0863
site	13	9.9	0.8	4.5	9.49e-06 ***
Residuals	86	14.7	0.2		

Values with codes: '***' were significant

The AEZ was not a significant contributory factor to the variation of honey harvests (Table 7-3); it however accounted for up to 29.32% of the observed variation and 12.93% was due to other unknown factors not explicitly included in the ANOVA terms.

Out of the 136 pair wise comparisons between sites in the study only 14 returned significant differences (Table 7-4). The result also showed significant differences in honey production for sites from within and between different AEZs.

Table: 7-4 A pair wise comparison of average honey production per hive between different sites

comparison	estimate	conf.low	conf.high	adj.p.value
nak5-kab2	-1.2140629	-2.41529289	-0.012832896	0.0448345968
nak5-kab3	-1.2070235	-2.40825353	-0.005793536	0.0476069533
lira4-lira1	-0.6701856	-1.31427348	-0.026097818	0.0328098528
nak5-lira1	-1.1628840	-2.09335274	-0.232415234	0.0027878694
nak5-lira2	-1.1714478	-2.29509562	-0.047800074	0.0321103048
lira4-lira3	-0.7558063	-1.49140642	-0.020206141	0.0376631069
nak5-lira3	-1.2485046	-2.24451192	-0.252497324	0.0026580766
nak2-lira4	0.9639092	0.06298671	1.864831702	0.0238659061
nak3-lira4	0.9324166	0.21754175	1.647291427	0.0013723576
nak5-nak1	-1.1919719	-2.31561964	-0.068324099	0.0263683720
nak5-nak2	-1.4566075	-2.58025532	-0.332959773	0.0015247297
nak4-nak3	-0.7076887	-1.40121920	-0.014158277	0.0405430883
nak5-nak3	-1.4251149	-2.40591512	-0.444314746	0.0001780954
tor4-nak5	1.1615393	0.16553200	2.157546596	0.0078663326

7.5 Discussion

A total of 75 plant species belonging to 31 plant families were identified in this study. Most of these plants comprised of shrubs trees, weeds and grasses. The most visited plants were in the Family Fabaceae followed by Asteraceae. Each studied site had a considerable number of plants foraged on by the bees. This is similar to findings of Abdullahi et al. (2011), Dukku (2013) and Kangave (2015). Kangave 2015, in Uganda identified 46 bee forage plants belonging to 20 plant families. Abdullahi et al. (2011) and Dukku (2013), in their studies in Nigeria where Fabaceae was recorded as the most visited by the honey bee *Apis mellifera*.

The findings of our study that show significant differences in dominance cover² of the plant species foraged by the bees at both the apiary/site location and the AEZs (Table 7-1) implying that there are dissimilarities in dominance cover of bee forage plant species which may either be uniform, clumped or randomly dispersed and this is seen more at AEZ level. This large dissimilarity (95.32%) was apparent in three compared AEZs except for Mid North and Lake Victoria Crescent comparison (Table 7-2).

The small residual contribution (1.63%) to the variations in dominance cover of the plant species foraged by the bees could be due to effects of land use (Kalema & Witkowski, 2012; Omer et al., 2015) and environmental factors (Eilu et al., 2004). The findings of Kalema & Witkowski (2012) on species diversity response to three main land uses (grazing, cultivation and charcoal production) in Nakasongola District, central Uganda, show that species diversity and richness in savanna is to a great extent influenced by land use and anthropogenic disturbances. According to Eilu et al. (2004), rainfall, soil PH and altitude are presumed to be important in influencing species diversity in Albertine Rift in western Uganda.

Our study shows significant differences in average honey harvested at the site (apiary) location (Table 7-3); the dissimilarity (57.74%) was actually contributed by 14 apiary sites (Table 7-4) within and between different AEZs. The significant difference in production between apiaries of Lake Victoria Crescent and Mid North AEZ (nak5-lira3, nak2-lira4, nak3-lira4, nak5-lira1, nak5-lira3 and nak5-lira2) (Table 7-4); is not caused by bee forage; the two AEZs had similar bee forage cover (Table 7-2); nak2 and nak3 apiary sites had higher production than lira4 site while nak5 had no production as compared to sites lira1-3. This finding shows that other apiary factors are the possible causes for the differences in average honey production per hive in Lake Victoria Crescent and Mid North AEZ which was attributed to honey bee pests, viruses and management.

Our findings agree in part with work done in Uganda by (Kajobe et al., 2016; Amulen et al., 2017; Kasangaki et al., 2018). Kasangaki et al. (2018) reports Mid North AEZ as having the strongest colonies with high productivity compared to Lake Victoria Crescent AEZ. Amulen et al. (2017) reported a zero detection of pesticides in Mid North AEZ, which according to the authors could result in high honey production.

² Dominance cover of plant species here refers to dominant/prominent

The significant difference in honey production between sites; Kyoga plains and Lake Victoria Crescent (tor4-nak5) (Table 7-4); reflect 0.0 Kg of honey harvested at nak5 and an average of 6.87Kg per hive harvested at tor4, which was attributed to differences in forage cover, poor apiary management practices and pests observed at nak5. Kajobe et al. (2016) showed pests affecting honey bee colonies and productivity in Uganda.

We found production differences between sites of Western highlands and Lake Victoria Crescent AEZs (Table 7-4); (nak5-kab2 and nak5-kab3); there was higher average honey yield per hive for kab2 and kab3 (19kg/hive and 14 kg/hive) respectively with no production at nak5. This finding is attributed to other factors (poor apiary management practices and pests observed) at site nak5 and high elevation at kab2 and kab3; the forage cover of the two AEZs, Highlands and Lake Victoria Crescent were significantly different (Table 7-2). This finding in part agrees with the findings of Asensio et al. (2016) who found high productivity of apiaries associated with elevation.

7.6 Conclusion

Seventy five (75) bee forage plants were documented. The dominant forages in an apiary location contribute to the observed honey production differences. The honey production differences found between sites of different AEZs; Kyoga Plains and Lake Victoria Crescent is attributed to differences in forage cover. The possible causes for the observed average honey production differences per hive in sites of AEZ with similar bee forage cover is attributed to other site (apiary) factors e.g. honey bee pests, viruses and management. We suggest that the dominant bee forage where an apiary is located, and how colonies are maintained influences the amount of honey harvested. Therefore we conclude that beekeeping can be done anywhere in Uganda as long as good forages are provided and other factors such as pests are managed according to good apicultural practice.

CHAPTER EIGHT

GENERAL DISCUSSION

8.1 Summary

This study was designed to provide an understanding on the factors affecting honey production in Uganda as a contribution towards achieving the solution to honey production increase. MAAIF/UBOS (2010) in Uganda reported an average production per colonized hive of 3.9Kg/hive; while (Haftom & Awet, 2013) in Ethiopia reported a potential productivity of modern hives at 22.8 Kg/hive and KTBH at 17.8 Kg/hive. The study focused on determining: socio-economic factors of beekeepers, honey bee pests, bee viruses and available bee forages.

Surveys and hive inspections made in four agro-ecological zones practicing beekeeping (the Western highlands, Lake Victoria Crescent, Kyoga plains and North East savannah) revealed; Seven socio-economic factors that significantly influence honey production namely; gender, district, beekeeping experience, market availability, beekeepers with records, ranking beekeeping in income generation and types of hives kept per farmer. Co-infestations of pest species in honey bee colonies; honey bee viruses in Uganda's bee colonies with CBPV impacting on colony sizes; and differences in agro-ecological zones in terms of honey production and bee forage species dominance.

Chapter 4 of this thesis presents the socio-economic factors that influence honey production in Uganda. This chapter explains how the seven factors affect honey production. It talks about honey production being highest among beekeepers ranking honey production as first position among their income generating activities and among beekeepers with only traditional hives compared to those with modern bee hives. It also shows that the bee keeping trainings received are not being translated into honey production increase. The chapter also discusses how the production of honey does not increase with increasing number of colonized hives kept per farmer.

In this thesis, findings on the honey bee pest study are discussed in chapter 5. This chapter shows the distribution of the different pests in the studied regions. This chapter also discusses co-infestations with 2-4 pest species in one honey bee colony and reports the presence of the death

head hawk moth, *Acherontia atropos* and *Oplostomus haroldi* in Lira and Nakasongola Districts and a significant increase in number of infested honey bee colonies observed with *Oplostomus haroldi* and rats. This chapter also shows a negative mean difference in honey production in 8 months associated to co-infestations of pests.

The bee viruses circulating in Uganda's bee colonies are discussed in Chapter six of this thesis. In this chapter, five bee viruses were detected in tested samples; BQCV, ABPV, SBV, CBPV and DWV. with CBPV presence correlated with colony strength and its prevalence highest (20.4%) in this study. This chapter also discusses co-infections with 2-4 different bee virus species in one honey bee colony.

Bee forages responsible for honey production are discussed in chapter 7. This chapter shows dominant plant species intensively visited by the bees in the dry and rainy seasons in the four agro-ecological zones. This chapter also talks about the apiary location as the main contributor to honey production.

8.2 Implications of these research findings

The high production of honey by beekeepers with traditional hives as compared to beekeepers with modern hives disagrees with the findings of Haftom and Awet (2013), Beyene & Verschuur (2014), and Gebiso (2015) where the average honey productivity of modern hives was higher than local hives. This finding brings in the element of hive management; the management system of traditional hives is totally different from that of modern hives (Kumsa & Takele, 2014). Uganda's beekeepers should prioritize beekeeping as an income generating activity and equip themselves with skills for managing modern hives. Increasing the number of colonies not resulting in production increase implies other factors (such as pests, forages) not included in the socio-economic study contributing to the low production of honey in colonies.

The distribution of honey bee pests in Uganda (Figure 5-1) is useful in their management and control. The multiple pests in honey bee colonies in Uganda found in this study suggest formulation/design of control methods for multiple honey bee pest species in one bee colony. The findings also suggest early detection and control of pests as a way to limit the impact of pests on honey production.

The finding in this study in which infected colonies with BQCV, ABPV, DWV and SBV did not show any symptoms, is also reported by Antúnez et al. (2006) in Uruguay where colonies infected with bee viruses that did not show any symptoms but eventually died after the study. This implies that there should be a plan to monitor the viral status of bees and their impact for management purposes. The recent invasion of Uganda's honey bee colonies with CBPV that seems to affect colony strength and the high prevalence of infected honey bee colonies with CBPV shows that its prevalence could be increasing in Uganda's bee colonies as described by Traynor et al. (2016). This has implications to our findings in that more colonies will weaken thus affecting honey production. We suggest that beekeepers should be sensitized on how to handle bees and their products to reduce the transmission of the bee virus diseases

The higher honey production per hive in Western highlands and Mid North AEZs compared to Kyoga plains (Chapter 7) can be attributed to available bee forages while the lower production per hive observed in Lake Victoria Crescent is attributed to pest infestations. According to Alghamdi et al. (2016) for a colony to produce a surplus of one kilogram of honey consumption of two kilograms of honey (for brood rearing and energy fuel for foragers) is required. The bee forage species (indigenous trees and shrubs) in Lake Victoria Crescent AEZ cannot produce more nectar to counter the honey consumed by pests, management of pests in this zone is essential for increased honey production.

Bee keeping practice can be done in any of the four studied AEZs, only the apiary site affects honey production since results showed differences in production between and within AEZ. Communities deriving their livelihoods for food and income through farming *Sesamum indica*, *Helianthus annuus*, *Cajanus cajan* and *Musa paradoxica* to exploit beekeeping as another livelihood strategy.

8.3 Recommendations for future research/action/policy/change

The findings of this study raise a number of opportunities for future research. There are still knowledge gaps that need to be addressed in order to refine and elaborate on these findings. These include:

- Studies on seasonal populations and control of the different species of large hive beetles (*Oplostomus sp*) and *Acherontia atropos*

- Determination of the carrying capacity or the maximum number of honey bee colonies that can be supported by different environments in Uganda without affecting the production potential of individual honey bee colonies
- The contribution of a plant species to honey productivity in honey bee colonies done under a closed environment with one species.

Recommendations for policy makers

- A protocol should be developed for monitoring the viral and honey bee pest/parasite status to provide data on bee health for management purposes
- Capacity building of stakeholders and bee keepers on how to handle bees and their products should be undertaken in order to reduce the transmission of the bee virus diseases
- Beekeeping trainings should be geared towards utilization of modern skills in the management of modern hives for increased honey production and population of bees.
- There is need to design control methods for multiple honey bee pest species in a single bee colony.
- The immediate action that needs to be undertaken by policy makers is; the management of Large hive beetles (*Oplostomus Spp*) in the Lake Victoria Crescent and Mid North agro-ecological zones

8.4 My contribution to knowledge

The result of this study is a contribution to biology towards understanding of the causes of low honey production faced by the bee keeping industry in Uganda.

In this study seven socio-economic factors were found to influence honey production in Uganda viz gender, district location, ranking of bee keeping in income generation, types of hives kept per farmer, beekeeping experience, market availability and keeping records while number of colonies kept and bee keeping trainings received not translated into honey production

This study reports co infestations of honey bee pests in a single bee colony and their populations over time impacting on honey bee colony strength

This study adds Chronic Bee Paralysis Virus (CBPV) as a new bee virus in Uganda's bee colonies, to the previously found bee viruses by Kajobe et al. (2010) and Chemurot (2017).

This study also shows that where the apiary is located and the bee forages there in influence the honey harvested per hive.

8.5 Intension to disseminate the research findings in this thesis

This work is to be published in peer reviewed journals and presented in conferences for the consumption of the scientific community. A dissemination workshop will be also organised for the beekeepers and stakeholders who participated in the the study. For the public; posters and leaflets from this work will be printed for dissemination in agriculture shows and exhibitions.

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APPENDIX

Appendix A: Questionnaire used for assessing objective 1

Questionnaire No.....

QUESTIONNAIRE FOR HONEY PRODUCERS IN SOROTI, LIRA, NAKASONGOLA, AND KABAROLE DISTRICTS, UGANDA

Interviewer.....respondent..... Phone contact..... Date

Part 1: Location

1.1 Village..... 1.3 Sub-county.....

Parish..... 1.4 County.....

1.5 District 1.6 GPS.....

Part 2: Household and general information

2.1 Respondent's name..... 2.2 Sex: (1 = Male, 2 = Female)

2.2 Relationship to honey producer: (1= Head, 2 = Spouse of Head, 3 = Child, 4 = Worker, 5 = other)

2.3 Age of honey producer (1 = Under 30 yrs, 2 = 31 – 40 yrs, 3 = 41- 60 yrs, 4 = over 60 yrs)

2.4 Land size (in acres) effectively used for honey production.....

2.5 Main sources of Income Rank (Food crops = Livestock =, Cash crops =, Business =, Salary =, honey production=, others (specify.....)

2.6 How much time in a week do you spend in the apiary?

Part 3: Equipment (bee hives)

3.1 What type of hives do you keep? (Indicate the type in the table below)

3.2 How many hives of each type are sited in your apiary? (Indicate the type in the table below)

3.3 How many of these hives are colonised? (Indicate the type in the table below)

3.4 How many hives have absconded in the last 6 months? (Indicate the type in the table below)

Hive Type	No of hives	How many hives are colonized now	How many hives have absconded in the last 6 months
Traditional			
Top bar			
Langstroth			
Johnson			
others			

Why do you keep these types of hives? (State the reasons in the table below)

.....

Part 4: Markets and marketing of honey

4.2 How many times do you harvest honey in a year?.....

4.3 How much honey did you harvest in the last three seasons?.....

.....

4.4 How much money do you get from the sale of honey per season?

4.5 Is the market for your honey readily available? 1= Yes 2= No.....

4.6 If yes, who are your major customers?.....

.....

4.7 If No, why is the market for your honey not readily available? ...

.....

4.8 Do you have any contractual agreements with buyers of your honey? Y/N.....

4.9 If yes, what are your obligations?.....

4.10 If no why?.....

4.11 In which period of the year that you sell most of your honey?

.....

4.13 Give the reasons why you sell more honey in that period?

.....

4.14 What factors influence the price of your honey?

i).....ii).....

iii).....

iv).....v).....

4.15 Is the current price of honey offered to you realistic? 1=Yes 2= No

4.16 If yes, why do you think it is realistic?

.....

4.17 If No, why do you think it is not realistic?.....

.....

4.18 Which honey properties are preferred by your buyers?

.....

Part 5 Training and beekeeping Experience

5.1 Have you ever been trained in honey production? 1 = Yes, 2 = No

.....

5.2 If yes, in what aspects of honey production?

.....

5.3 If Yes, how many times have you been trained on honey production

.....

5.4 Who provided the training?

.....

5.5 How long was each training?

5.6 Do you keep any records of honey production? 1 = Yes, 2 = No.....

5.7 If yes, which records do you keep and why?

.....

.....

5.8 If No, why?

.....

5.9. Where do you get information on production of honey? Rank 1= government 2= family member 3= radio 4= farmer groups 5=NGO 6= magazines 7= other farmers, 8 = others (specify)

5.10 Have you received training on how to control honey bee pests and diseases
Yes.....No.....

5.11 If yes, which organisation / individual conducted the training?

.....

5.12 Formal Education level: primary.....

..secondary.....tertiary.....

5.13 Years of Beekeeping experience.....

Part 6 honey bee pests, predators, pathogens

6.1 List the honey bee pests that affect colonies in your area beginning with the one causing most damage

.....

.....

6.2 List the honey bee diseases that affect colonies in your area beginning with the one causing most damage

.....

.....

6.3 Among the types of hives (Traditional, Top bar and Langstroth) which type is the most affected by honey bee pests and disease? List starting with the most affected.

.....

.....

6.4 Why do you think this type of hive is most affected by honey bee pests and disease?

.....

.....

.....

6.5 Please fill in the table in order to determine the prevalence of pests affecting honey bee colonies in your area

No.	Honey bee pest	Most common	Common	Not common
1				
2				
3				
4				

6.6 Please fill in the table in order to determine the prevalence of diseases affecting honey bee colonies in your area

No	Honey bee disease	Most common	Common	Not common
1				
2				
3				
4				
5				

6.7 Record the average Kg of honey you harvest with or without honey bee pests and diseases infection

No.	Type of hives	Average weight (Kg) without pests and disease infection	Average weight (Kg) with pests and disease infection
1	Traditional hives		
2	Top bar hives		
3	Langstroth hives		

6.8 How many colonies in your apiary are affected by small hive beetles but remain productive

.....

6.9 Which pest control methods do you practice in your apiary?

.....

Appendix B: Plant species foraged by the bees in the study areas

Family	Species Name	Plant form	Bees seen collecting	Flowering time
Acanthaceae	Asystasia gangetica .	shrub	N+P	
Anacardiaceae	Lannea barteri	tree	N+P	
	Mangifera indica	tree	N+P	drought
	Rhus natalensis	shrub	N+P	
Apocynaceae	Carissa edulis	shrub	N	rainy
	Thevetia peruviana	shrub/tree	N	rainy & drought
Arecaceae	Borassus aethiopicum	palm tree	P	
Asteraceae	Bidens pilosa	herb	N+P	rainy
	Bidens steppia	herb	N+P	rainy
	Conyza sumatrensis	herb	N+P	rainy
	Galinsoga parviflora	herb	N+P	rainy
	Guizotia scabra	perennial/herb	N+P	rainy
	Heliopsis annuus	herb	N+P	rainy
	Tithonia diversifolia	Shrub	N+P	rainy
	Vernonia adoensis .	shrub	N+P	drought
	Vernonia sp.	shrub	N+P	drought
Bignoniaceae	Jacaranda nimonsifolia	tree	N+P	rainy & drought
	Markhamia lutea	tree	N+P	rainy & drought
Casuarinaceae	Casuarina equisetifolia	tree	P	
Celastraceae	Maytenus senegalensis	shrub/tree	N+P	
Cleomaceae	Cleome gynandra	herb	P	
Combretaceae	Combretum collinum	tree	N+P	drought
	Combretum molle	tree	N+P	drought
Cucurbitaceae	Cucurbita ficifolia	climber	N+P	
	Cucurbita maxima	climber	N+P	
Ebenaceae	Euclea divinorum	shrub	N+P	
Euphorbiaceae	Bridelia micrantha	tree	N+P	
	Flueggea virosa	shrub	N+P	
	Manihot esculenta	shrub	N+P	
Fabaceae	Acacia brevispica	shrub	N+P	drought
	Acacia hockii	shrub	N+P	drought
	Acacia polyantha	tree	N+P	drought
	Albizia coriaria	tree	N+P	drought
	Albizia ferruginea	tree	N+P	drought
	Albizia grandibracteata	tree	N+P	drought
	Bauhinia purpurea	shrub	N+P	drought
	Caesalpinia decapetala	shrub	P	rainy

Family	Species Name	Plant form	Bees seen collecting	Flowering time
	Caesalpinia pulcherrima	shrub/tree	N+P	rainy & drought
	Cajanus cajan	shrub	N+P	
	Calliandra calothyrsus	tree	N+P	rainy & drought
	Crotalaria cleomifolia	shrub	N+P	
	Delonix regia	tree	N+P	drought
	Erythrina abyssinica	tree	N+P	drought
	Piliostigma thonningii	shrub	N+P	rainy
	Tamarindus indica	tree	N+P	drought
Lamiaceae	Hoslundia opposita	shrub	N+P	rainy
	Hyptis suaveolens	shrub	N+P	rainy
	Leonotis ocymifolia	woody herb	N	rainy
	Ocimum gratissimum	Herb	N+P	rainy
	Ocimum tenuiflorum	Herb	N+P	rainy
Loganiaceae	Strychnos innocua	shrub/tree	N+P	
Malvaceae	Sida acuta Burm	woody herb	N+P	rainy
	Urena lobata	woody herb	N+P	rainy
	Grewia mollis	shrub	N+P	rainy
Meliaceae	Azadirachta indica	tree	N+P	rainy
Moringaceae	Moringa oleifera	tree	N+P	rainy
Musaceae	Musa paradoxical	perennial herb	N+P	rainy/ drought
Myrtaceae	Callistemon citrinus	tree/shrub	N+P	rainy & drought
	Eucalyptus sp.	tree	N+P	rainy & drought
	Syzygium cumini	tree	N+P	rainy
Passifloraceae	Passiflora edulis	climber	N+P	rainy
Pedaliaceae	Sesamum indica	herb	N+P	rainy
Poaceae	Zea mays	annual grass	P	rainy
Rubiaceae	Vangueria apiculata	shrub	N+P	drought
Rutaceae	Citrus aurantifolia	shrub/tree	N+P	drought
	Clausena anisata	shrub/tree	N+P	rainy
	Zanthoxylum chalybeum	shrub/tree	N+P	drought
Simaroubaceae	Harrisonia abyssinica	shrub/tree	N+P	drought
Solanaceae	Brugmansia hybrid	shrub	N+P	rainy
	Brugmansia suaveolens	shrub	N+P	rainy
	Solanum incanum	herb	P	rainy
Tiliaceae	Triumfetta cordifolia	woody herb	N+P	rainy
Verbenaceae	Stachytarpheta jamaicens	herb	N	rainy & drought
	Vitex doniana	tree	N+P	drought

Family	Species Name	Plant form	Bees seen col- lecting	Flowering time
Vitaceae	Cyphostemma adenocaulis	climber	N+P	