FIELD ABUNDANCE OF *SERANGIUM PARCESETOSUM* (COL., COCCINELLIDAE), A PREDATOR OF CASSAVA WHITEFLY (HOM, ALEYRODIDAE) IN TWO CASSAVA GROWING AGRO-ECOLOGICAL ZONES OF UGANDA

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DEDICATION

I dedicate this research work to my dear wife, Karungi Moureen Wamani, together with my mother, Harriet Birungi and above all the Almighty God who has always guided me.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFLP	Amplified Fragment Length Polymorphism
B. tabaci	*Bemisia tabaci*
CBSD	Cassava Brown Streak Disease
CMD	Cassava Mosaic Disease
DNA	Deoxyribonucleic acid
Faostat	Food and Agricultural Organization Statistics
M.Sc	Master of Science
MAP	Month after Planting
mm	millimeters
mtCO1	Mitochondrially Encoded Cytochrome C Oxidase I
NaCRRI	National Crops Resources Research Institute
PCR	Polymerase Chain Reaction
RAPD	Randomly Amplified Polymorphic DNA
RCBD	Randomized Complete Block Design
RNA	Ribonucleic acid
S. parcesetosum	*Serangium parcesetosum*
T. vaporariorum	*Trialeurodes vaporariorum*
^{0}C	Degrees Celsius

ABSTRACT

The whitefly, *Bemisia tabaci*, is a major pest of cassava in Africa where it causes direct feeding damage on the leaves and indirectly through sooty mould production. This pest is also a vector of cassava mosaic begomoviruses and cassava brown streak viruses which are main production constraints to cassava in sub-Saharan Africa. Much as numerous efforts have been made to control CBSD and CMD in Uganda, mainly through breeding of resistant varieties, limited effort has focused on controlling the vector directly. The use of synthetic pesticides to control whiteflies on cassava is also ineffective, not economical and causes adverse effects on the environment. Therefore, there is need to develop an integrated approach in the management of this pest with predator (*Serangium parcesetosum)* being explored as an option. This research was carried out to provide more information on this predator so as to bridge the knowledge gap towards its positive use in controlling whiteflies in cassava. A study was conducted to ascertain the abundance of *Serangium parcesetosum;* a predator of cassava whitefly, its field relationship with the prey as well as the influence of climatic factors on its population. This trial was established in two agro-ecological zones of Uganda, namely; North Western Savannah Grassland (Lira) and the Kyoga Plains (Kamuli) in the first rains of 2017. Results revealed that both mean adult and larvae of *Serangium parcesetosum* per plant were more abundant in Kamuli (4.92 and 11.75) as compared to Lira (0.39 and 0.51) respectively. Improved broad-leafed cassava varieties; Narocass1 and Nase 14 were more preferred by *Serangium parcesetosum* than the slender long leafed landrace, Njule red. However, there was no significant difference between the varieties in Lira ($P < 0.489$) and Kamuli ($P < 0.598$) respectively. Irrespective of location, 27% and 30% increment in the mean adult and larvae *Serangium parcesesotum* population per plant was registered respectively and this was attributed to the mean whitefly nymph population per plant observed. In both locations, a slight increment in the *Serangium parcesesotum* population per plant was associated with the mean maximum monthly temperature. A similar trend was recorded with the total monthly rainfall in Kamuli while the reverse was true for Lira where, 14.3 % ($p< 0.460$) and 16.6 % ($p<0.422$) decrease in the mean adult and larvae *Serangium parcesesotum* population per plant respectively was registered. Generally, this study revealed that agro-ecological zone (location) and cassava age were the main drivers of whitefly population which directly influenced the *Serangium parcesesotum* population observed. Rainfall and temperature were also reported to influence the predator population but at minimal level

CHAPTER ONE

GENERAL INTRODUCTION

1.0 Introduction

This chapter discusses the background of the study, problem statement, general and specific objectives. It also states hypotheses as well as significance of the study.

1.1 Background

1.1.1 Cassava: its importance and production constraints

Cassava (*manihoti esculenta*) was introduced into Buganda by Arab traders through Tanzania between 1862 and 1875 and it quickly spread to other parts of the country (Langlands, 1972). Cassava is ranked second to bananas in the country in terms of area occupied, total production, per capita and Uganda is the sixth largest producer in Africa producing about 4.2 to 5.5 million metric tons (MAAIF, 2011). It is an important staple food crop for many people in Uganda especially for West Nile, Northern and Eastern regions. Cassava is also widely grown in other parts of the country as a famine reserve crop. This is attributed to its high yielding capability, easiness to grow and good performance in marginal areas. According to Mugisa (2010), cassava, which is known as a "poor man's crop", is predominantly grown by subsistence farmers as a staple crop on plots averaging 1 to 3 acres. About 30% of the total production is marketed in form of fresh tubers or value-added products like dried chips, flour and alcohol (Kimathi *et al*. 2014). In Uganda, cassava is usually grown as a sole crop or as an intercrop of legumes (beans, peas, soybean) or cereals (maize, millet, sorghum) among the smallholder farmers.

According to Faostat (2011), Uganda's national cassava average yield (14 tons per hectare) is way below the potential yield of about 30-40 tons per hectare. This yield penalty is attributed to a

number of factors that challenge production and utilization of the crop. These include; the use of inferior and low yielding varieties, lack of good quality planting materials, pests and diseases, deteriorating land availability and soil conditions, lack of credit facilities and farm inputs, poor price incentives, labor bottlenecks and poor cultural practices, bitterness and cyanogenic glucosides, bulkiness and perishability of the crop, poor methods of processing (Otim-Nape and Zziwa, 1990).

Pests and diseases are the most important cassava production constraints as they reduce yields substantially, posing a threat to food security throughout the developing countries (Beatriz. V. Campo *et al*., 2012). Major cassava pests include; whitefly (*Bemisia tabaci*), cassava mealy bug (*Phenacoccus manihoti*), cassava green mite (*Monochyellus tanajoa*), red spider mite (*Tetranychus spp*), cassava scale (*Aonidiomytillus spp*), termites, ants and rodents. Cassava brown streak disease (CBSD), cassava mosaic disease (CMD), cassava bacterial blight (CBB) and leaf spot are the important diseases. However, according to Maruthi *et al*. 2014, cassava brown streak and cassava mosaic diseases stand out as the most important diseases.

According to the Pest and Disease Survey carried out by National Crops Resources Research Institute (NaCRRI) in 2013, Cassava whitefly (*Bemisia tabaci*) emerged as the most important cassava pest in Uganda and its population is rapidly increasing in terms of numbers and spread over the years. Most farmers in Uganda have ventured into the use of synthetic pesticides to control whiteflies on cassava. This method is however ineffective, not economical and may cause adverse effects on the environment. Therefore, there is need to develop an integrated approach to the management of this pest with predators being explored as an option.

1.2 Problem statement

Cassava whitefly (*Bemisia tabaci*), the most important cassava pest in Uganda is rapidly increasing in terms of numbers and spread (NaCRRI, Pest and disease survey, 2013). Signs of the direct damage caused by high population of whiteflies include; leaf chlorosis, a mottled appearance, reduction in plant vigor, general plant stunting and induction of phytotoxic disorders (Bedford *et al*. 1994). In addition, indirect damage is caused through production of honeydew that culminates into growth of sooty mould on leaves, petioles and stems. According to Legg *et al*. 2003, both direct and indirect whitefly damage may result in crop yield reduction of up to 50% in susceptible cassava varieties. The whitefly is also a known vector of *Gemini* and *Ipomo* viruses that cause cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) respectively. These two diseases are reported to cause loss of up to 24 million dollars annually and regarded as the biggest cassava production constraint in Uganda (New Vision Newspaper ,17th November, 2015). Also, high whitefly population has been greatly associated with the spread of these two viral diseases (Hillocks, 2003).

Much as numerous efforts have been made to control CBSD and CMD in Uganda, mainly through breeding of resistant varieties, limited effort has focused on controlling the vector directly. More to that, the improved varieties are increasingly becoming susceptible to whitefly attack. The use of synthetic pesticides to control whiteflies on cassava is also ineffective, not economical and causes adverse effects on the environment. Therefore, there is need to develop an integrated approach to the management of this pest with predators being explored as an option. Studies by Otim (2006) identified a new species of Coccinellidae specialist predator for cassava whitefly called *Serangium parcesetosum* and it was found distributed and naturally occurring among some cassava fields in central Uganda. More to that, there is insufficient

information about the abundance of *Serangium parcesetosum,* its field relationship with the prey on cassava as well as the influence of climatic factors on its population in Uganda. This research is intended to carry out more investigations on this predator and to bridge the knowledge gap towards its positive use in controlling whiteflies in cassava.

1.3 General objective

To evaluate the development of biological control options of cassava whiteflies using *Serangium parcesetosum,* a naturally occurring predator of cassava whitefly found in cassava fields in Uganda.

1.4 Specific objectives

I. To determine the abundance of *Serangium parcesetosum;* a predator of cassava whitefly, in two distinct agro-ecological zones of Uganda.

II. To evaluate the field relationship between *Serangium parcesetosum* abundance on cassava and whitefly population in the two distinct agro-ecological zones of Uganda.

III. To assess the influence of climatic factors (temperature and rainfall) on *Serangium parcesetosum* population in the two distinct agro-ecological zones of Uganda.

1.5 Research Hypotheses

I. There is no difference in the abundance levels of *Serangium parcesetosum* between the two cassava growing agro-ecological zones of Uganda.

II. There is no field relationship between *Serangium parcesetosum* abundance on cassava and whitefly population in the two cassava growing agro-ecological zones of Uganda.

III. Climatic factors (temperature and rainfall) have no influence on *Serangium parcesetosum* population in the two distinct agro-ecological zones of Uganda.

1.6 Significance of the study

The study will provide information that will help bridge the knowledge gap in the development of biological control options with special attention to *Serangium parcesetosum*, a specialist predator for cassava whiteflies in Uganda. This is meant to compliment the whitefly resistant varieties that are being developed, whereby the pest few populations harbored by these varieties will quickly be cleared or predated on by the predators. As a result, the whitefly and its associated damages will be controlled without adversely endangering the ecosystem. This will then guarantee increased cassava production, food and income security for the rural livelihoods since the pest damage and vector transmission of CMD and CBSD will be controlled.

1.7 Definition of Key Terms

Pest

This is a plant or animal detrimental to humans or human concerns including crops, livestock, and forestry. The term is also used of organisms that cause a nuisance, such as in the home.

Predator

This is an organism that primarily obtains food by the killing and consuming of other organisms (pests).

Agro-ecological Zone

This is a geographical area exhibiting similar climatic conditions that determine its ability to support rained agriculture. At a regional scale, this area is influenced by latitude, elevation, temperature, seasonality, rainfall amounts and their distribution during the growing season.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter examines the literature obtained from scientific published articles, reports which discuss the cassava whitefly, its biology, ecology and the damage it causes to the crop. The chapter further discusses the taxonomy, biology of *Serangium parcesetosum* as well as the different efforts made in its application for management of whitefly in the different countries.

2.1 The cassava whitefly

2.1.1 Taxonomy, diversity and distribution

The cassava whitefly, *bemisia tabaci* is classified from kingdom to family as follows; Animalia, arthropoda, insecta, hemiptera, sternorrhnycha, aleyrodoidea, aleyrodidae. The taxonomy of the family aleyrodidae was earlier based on the morphological variations of the fourth instar nymph resulting in description of the species of *bemisia* from different crop hosts and localities (Legg, 1994). According to Russel (1957), all these different species were then aggregated into one name *Bemisia tabaci.* This therefore demonstrated that the pupal characteristics were attributed to the host rather than the genome of the insect. In the mid-1990s in the Southwestern parts of United States of America, there was emergency of heterogeneity in the species of *B. tabaci* as a strain initially categorized as a single one actually developed significant biological differences and thus emerged a new strain from the first one. This new strain had rapid development rate, wider host range and high insecticide resistance (Cohen *et al*. 1992). Currently the species is regarded as a species complex with more than 34 genetic groups that are morphologically and biologically indistinguishable. According to Boykin (2014), these species can only be

differentiated using molecular tools. The most applied molecular techniques to study whitefly diversity are; DNA-based molecular techniques, like random amplified polymorphic DNA (RAPD) PCR fingerprinting (Gawel and Barlett, 1993; De Barro and Driver, 2000; Guirao *et al*. 1997), amplified fragment length polymorphism (AFLP) markers (Cervera *et al*., 2000), the mitochondrial DNA marker genes, mitochondrial cytochrome oxidase I- mtCOI (Simon *et al*. 1994; Frohlich *et al*. 1999; Brown *et al*. 2000), the ribosomal RNAs, 16SrDNA (Prokaryotes) (Clark *et al.* 1992; Frohlich *et al*. 1999) and 18SrDNA (eukaryotes) (Campbell *et al*. 1993) and protein polymorphism involving isozyme variation in esterases (Wool *et al*. 1990; Brown *et al*. 1995). According to Frohlich *et al*. (1999), genetic variability and evolutionary relationships among *B. tabaci* from different geographical locations and host-plant species has been studied using mtCOI marker. Two distinct cassava-associated *B. tabaci* clusters were studied in Uganda using this marker and generated Uganda 1 (Ug1) and Uganda 2 (Ug2) with Ug1 suggested to be the indigenous while the Ug2 as an 'invasive' population (Legg *et al*. 2002). Dinsdale *et al*. (2010) identified five putative species in Africa which included Sub-Saharan Africa (SSA) 1 to 5. He found out that SSA1 was the most widely distributed while SSA2 was confined to East and West Africa, SSA3 in Cameron and Togo while SSA5 was only restricted to South Africa. SSA1 was later sub divided into subclades 1to 4 (Legg *et al*. 2002). In Uganda, a study carried out by Habib Mugerwa on geographical distribution of *B. tabaci* genotypes in 2013, the SSA1 sub-clade II genotypes were more abundant than SSA1 subclade I with the latter being mainly localized in the western part of the country.

2.1.2 Biology and Ecology

The whiteflies lay their eggs underneath the top young tender leaves where they feed from. These eggs are laid in spiral patterns or arcs, sometimes in parallel arcs. The eggs are elongated

in shape, with one narrow end produced into a pedicel, which in some species is longer than the rest of the egg. After fertilization, the pedicel shrivels into a stalk (Gill,1990). The eggs hatch to release first instars which possess functional legs able to move quickly in search of available minor veins and upon reaching the appropriate phloem they remain sessile till adult stage (Byrne & Bellows, 1991). Once the first instar has inserted its stylets into the phloem to feed, it settles down and no longer uses its legs, and they degenerate after the first ecdysis. From then until it emerges as an adult, it remains attached to the plant by its mouthparts. The final instar feeds for a while, then undergoes changes within its skin, ceasing feeding and growing a new skin, forming what amounts to pupa. In doing so the insect does not shed the larval skin, which it retains as a protective puparium and which dries out. Meanwhile, the pupa in the skin develops into a pharate adult that usually is visible through the wall of the puparium (Comstock, 1949). The second and third instars resemble each other and differ in size (Gill, 1990; Fishpool and Burban, 1994) while the fourth instar or 'pupa' (Lopez-Avila, 1987; Byrne and Bellows, 1991) is shield shaped, broadly elliptical (Gill, 1990) with two red eye spots at the anterior end visible beneath the translucent integument (Von Arx *et al*. 1983). The adults then emerge out of the split puparium. According to Ridley (1989), the female adults are usually bigger in size (1mm) compared to the males (0.8mm). The developmental time from egg to adult of whitefly is significantly different according to the host plant it feeds on and temperature within that locality (Coudriet *et al*. 1985). From the egg to the adult, developmental times were 107 days on cotton in India (Husain and Trehan, 1933), 14.5 days on aubergine in Israel (Avidov, 1956), 18.6 days on sweet potato, 29.8 days on carrot in the laboratory (Coudriet *et al*. 1985), and averaged 21 and 28 days for dry and rainy season respectively on cassava in Ivory Coast (Fishpool *et al*. 1995). Each female has the capacity to produce about 300 eggs in its life span. These species reproduce

parthenogenetically (Liburd *et al*. 2008). The unmated females produce haploid males while mated females produce both male and females (Byrne and Bellows, 1991). The ratio of male to female usually is 1:2 under field conditions and depends on host and host species, temperature and time of the year (Pruthi and Samuel, 1942; Sharaf and Batta, 1985). Females tend to have longer life span (35 days) than the males (20 days) (Ridley, 1989).

According to Otim-Nape *et al*. (1996), the adult whiteflies invade their host slowly establish and thereafter a small population appears after 3 weeks of the initial colonization followed by rapid buildup in 3 to 4 months after planting. This rapid buildup is attributed to the much available young tender foliage on the plant that the whiteflies enjoying feeding on. A steady population growth follows for a short period, followed by a rapid decline which is maintained throughout the rest of the crop's growth period (Fishpool and Burban, 1994, Fishpool *et al*. 1995). This decline is explained by the reduced food quality caused plant aging. Tuberisation is also another factor responsible for decline in whitefly population since the resultant changes in resource partitioning within the plant may adversely affect the nutritional quality of the aerial parts. In other words, food resources are devoted to aerial growth during the early growth period (1 to 3 months) and declines are observed after 4 to 5 months when the process of root tuberisation begins. The dispersal of whiteflies is by wind which enables them to travel short and long distances as well as movement of the nymphs in the planting materials facilitated by human beings (Byrne and Bellows, 1991). The variation in population of whiteflies were also attributed to the cropping systems which advocate for mixed cropping and intercropping (Fargette and Fauquet, 1988).

2.1.3 Damage caused by whitefly on cassava

Whiteflies cause direct, indirect damage to the plant as well as vectoring *Begomoviruses, Ipomoviruses* which cause CMD and CBSD (Legg *et al*. 2012). Direct crop damage occurs when whiteflies feed on plant phloem, removing plant sap which causes leaf chlorosis, a mottled appearance, reduction in plant vigour, general plant stunting and induction of phytotoxic disorders (Bedford *et al*. 1994). Whiteflies also excrete honeydew, which promotes sooty mold on leaves, stems and petioles that interferes with photosynthesis and damages harvest quality (Navas-Castillo *et al*. 2011). According to Legg *et al*. (2002), both direct and indirect whitefly damage may result in crop reduction of up to 50% in susceptible cassava varieties. Whitefly is also a major vector of viral plant diseases especially begomoviruses (Costa *et al*. 1993), and in Africa, it transmits cassava mosaic geminiviruses, which cause cassava mosaic disease (CMD) (Bock and Woods, 1983). This disease has resulted in devastating yield losses throughout cassava growing regions in Eastern and Central Africa with losses in Uganda estimated at several millions of US dollars at the height of the epidemic during the early 1990s (Legg and Ogwal 1998; Otim-Nape *et al*. 2001). The whiteflies vector two species in the *Ipomovirus* genus, cassava brown streak virus and the Ugandan cassava brown streak virus which are associated with CBSD (Mbanzibwa *et al*. 2011). CBSD causes major losses due to root necrosis and is a significant threat to cassava in East Africa (Hillocks, 2003; Mbanzibwa *et al*. 2011). However, transmission of this disease by whiteflies is low as infected plant cuttings are a more significant mode of transmission.

2.2 Serangium parcesetosum

2.2.1 Taxonomy, Biology and Ecology

According to Tronquet (2014), *Serangium parcesetosum* is classified as animalia, arthropoda, hexapoda, coleoptera, coccinellidae, *serangium, Serangium parcesetosum*. *Serangium parcesetosum* undergoes a development lifecycle of about 28 – 33 days depending on the temperature and food supply (Enchanted learning.com). The female usually lays tiny, light - yellow eggs in clusters of 10 to 50 on the underside of a cassava leaf. These eggs take about 3 – 5 days to hatch into larva stage which feeds vigorously, sheds its skin several times to give way to the pupa stage. This process of transformation from larva to pupa lasts about 21 days. Then within 7–10 days, the adult *Serangium parcesetosum* emerges out (www.stsd.org/webpages/animal/serangium*)*. Furthermore, the study carried out by Chakraborty *et al. (*2014*)* revealed that the first instar of *Serangium parcesetosum* had a duration period of 1 to 3 days and on an average of 1.71 ± 0.20 days, second instar lasted 1.50 to 3 days with the mean duration was 2.20 ± 0.16 days. 2 to 4 days was duration of third instar with mean duration of 3.10 ± 0.17 while the fourth instar developed within 3 – 5 days averaging 3.75 ± 0.19 days. Lastly, the pupal stage took 2 to 4 days with an average 2.60 ± 0.21 day. Also, a study carried out by Al-zyoud (2005) where he used *T. vaporariorum* as prey for *Serangium parcesetosum* raised on cucumber at high temperature of 30°C, there were no significant differences in the mean developmental duration of all stages between females and males. The egg stage took longer than each instar of the larval development, and it was a mean of 4.3 and 4.4 days. Among the different larval instars, the 4th one lasted longer than the other ones, where it took a mean of 3.5 and 3.1 days. The developmental duration of the pupal stage was the longest comparing to all immature stages of the predator, in which it was a mean of 5.5 and 5.2 days for females and

males, respectively. Mean total developmental duration from egg to adult emergence was not significantly different. His study further stressed that mortality occurred during all developmental stages of *S. parcesetosum*. Within egg stage, it was higher than each instar of the larval development and it valued 6.4%. During the larval instars, mortality in L1 was the highest with 5.8%, while for the L2, L3 and L4 it valued 2.6, 1.9 and 2.6%, respectively. While in the pupal stage, it was highest among all the other immature stages as it reached up to 7.1%. Total mortality during development from egg to adult emergence was 26.4%.

Samways *et al*. (1997) observed that the fecundity of females varied form 200-300 eggs with mean of 270.5 and with average 70.15% eggs were hatched. The researcher also noted that longevity of the male *Serangium parcesetosum* varied from 35 to 45 days with an average of 40.20 ± 1.00 days whereas, the longevity of the female varied from 45 to 53 days with an average of 47.50 ± 0.82 days. The average longevity of the beetle (male and female) were 43.85 ± 0.91 days. Al-zyoud (2005) also confirmed in his study when he recorded mean period of pre-oviposition as 8.8 days and a mean period of oviposition of 46.0 days for *Serangium parcesetosum* raised on cucumber at high temperature of 30°C. Generally, the mean period of post-oviposition was shorter than oviposition period and it lasted for 16.0 days while the mean total number of laid eggs by S. parcesetosum females valued 27.8 eggs.

Serangium parcesetosum is classified as a specialist predator and has been reported to prefer feeding on *B. tabaci* and *T. vaporariorum* compared to the other non-whitefly species. This was confirmed by Legaspi *et al*. (1996) who offered the predator simultaneous three prey choices namely; eggs of corn earworm, *Helicoverpa zea*, eggs of tobacco hornworm, *Manduca sexta* and eggs of cassava whitefly, *Bemisia tabaci.* reared on different plants. He later observed that *Serangium parcesetosum* didn't feed on the eggs of *H. zea* and *M. sexta* presented to it and

instead preferred *B. tabaci*. In another study carried out to ascertain the preference of *Serangium parcesetosum* for the different whitefly species, it was observed that whitefly species, *Paraleyrodes minei laccarino* is not suitable for *Serangium parcesetosum* development but *B.tabaci* and *D. citri* were suitable (Abboud and Ahmad 1998). These authors also noted that *Serangium parcesetosum* developed significantly faster on *B.tabaci* than on *D.citri* and thus indicating the preference towards *B. tabaci*. The same views are shared by Al-Zyoud and Sengonca (2004) who mentioned that *Serangium parcesetosum* preferred whitefies rather than thrips, aphids and mites, and the predator revealed more preference for *B. tabaci* than *T. vaporariorum*. This therefore confirms *Serangium parcesetosum* as a specific predator to *B.tabaci*.

2.2.2 Research on *Serangium parcesetosum* in the management of whitefly

Serangium parcesetosum, a ladybird, was evaluated as a possible biological control agent of *B. tabaci's* winter and spring populations which infests eggplants grown undercover in Turkey (Kutuk *et al*, 2008). It was found that in winter, *S. parcesetosum* failed to control *B. tabaci*, even when the ladybird population was augmented six times over the course of the experiment. This contrasted with that observed in spring when, with only one introduction of the ladybird, control of the pest was gained within 3 weeks after release. In spring, the *B. tabaci* population in the cages receiving two and four *S. parcesetosum* adult per plant showed 56 and 53% reduction, respectively. The percent reduction in *B. tabaci* population rose to 98.6 and 98.3% in both cages, respectively, by the end of experiment. It is suggested that release of *S. parcesetosum* against *B. tabaci* during spring months may be offered as an alternative solution to increase implementation of biologically based *B. tabaci* management. In winter, other biological control agents are needed

and these need to be further explored. In another study, Al-Zyoud *et al.* (2006) evaluated the potential of *Serangium parcesetosum* as a biological control option for *B. tabaci* under screen house conditions. The team introduced *B. tabaci* to cotton plants in three cabins in average of 50 adults per plant. One and two weeks later, adult females and males of *S. parcesetosum* were introduced at a rate of one female and one male per plant in the first and second cabins, respectively.

The third cabin was considered as a control. The results showed that the mean number of whiteflies in the control cabin was found significantly higher than that of either when *S. parcesetosum* was introduced 1or 2 weeks after the infestation with the whitefly. Also, the mean number of *B. tabaci* was significantly higher when the predator was introduced 2 weeks rather than1 week after *B. tabaci* infestation. The maximum mean weekly number of whiteflies/plant was 192.3 in the second week, whereas it was 294.6 in the third week and 1136.4 in the fifth week, in first, second and control cabins, respectively. In the last experimental week, the mean weekly numbers were 74.7, 122.9 and 684.7 whiteflies/plant in the three cabins, respectively. *S. parcesetosum* had been successfully fed, reproduced and established its population on *B. tabaci* on cotton plants. The mean weekly number of the predatory individuals increased gradually with the progress of the experimental time. The results demonstrated that the maximum reduction percentage in *B. tabaci* population was 90.7 and 86.5% in the fifth week after *B. tabaci* infestation, when the predator was introduced 1 and 2 weeks after the infestation with the whiteflies, respectively. Nevertheless, it is speculated that an earlier release of *S. parcesetosum* would be more effective in the biological control of *B. tabaci*.

Another study to evaluate the lady beetle, *Serangium parcesetosum* for control of *Bemisia tabaci* on greenhouse eggplant in the Mediterranean region was carried out (Kutuk *et al*, 2008). This

study explored the control of *B. tabaci* on greenhouse eggplants following releases of the lady beetle *Serangium parcesetosum* Sicard (Coleoptera: Coccinellidae). In cage experiments, four adults per plant were introduced and, within 3–4 weeks, resulted in 97 and 98% reductions in whitefly populations in 2004 and 2005, respectively. In a large plot experiment, two adults per plant were released only one time. Beetle larvae were observed through 2–9 weeks after release. The density of whitefly in large plot receiving beetle adults showed fluctuations to a level lower than in control plot receiving no beetle in 2004 and 2006.

In conclusion, this chapter highlights the distribution and biological fitness of cassava whitefly. It also elaborates the importance of the pest to agricultural production ranging from vectoring the devastating Cassava Mosaic and Cassava Brown Streak Diseases to physically damaging the crop through direct feeding damage. Furthermore, the biological fitness, ecological adaptation of a lady bird beetle, *Serangium parcesetosum* as a predator to the cassava whitefly is discussed. Recent efforts exploring the use of the predator in the management of whiteflies are enlisted. However, there is a knowledge gap to be filled that highlights the population changes of *Serangium parcesetosum* in relation to varying environments, cassava varieties and age as well as ascertaining its relationship with the prey (cassava whitefly) in Uganda. This will be instrumental in guiding augmentation for possible release of *Serangium parcesetosum* to control cassava whiteflies

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

This chapter discusses the experimental sites, experimental design and field data collection. It further elaborates how the collected data was analyzed.

3.1 Experimental sites

Two field trials were established; one on farm trial in Nakakabala parish, Mbulamuti subcounty, Kamuli district and the other at Ngetta Zonal Agricultural Research and Development Institute in Lira district. These sites represent two important cassava growing agro-ecological zones of Uganda, namely Kyoga Plains and Northwestern Savannah Grassland respectively.

Kyoga Plains agro-ecological zone is characterized by sandy clay alluvial soils with moist semi-deciduous forest, savannas, and swamps. The area receives rainfall ranging from 1215mm to 1328mm with bimodal rains comprising of March to May for the first ones and October to December for the second rains. Temperatures range from 15^0c to 32.5^0c. Climate is warm and wet with relatively high humidity and average altitude of 1134m above sea level.

Northwestern Savannah Grassland is comprised of ferruginous sandy loam soils with intermediate savanna grassland and scattered trees. The rainfall received ranges averagely from 1340 mm – 1371mm with bimodal rains followed by a dry spell for about 5 months. Temperature and altitude range from 15 - 25 °C and 951 – 1341m above sea level respectively (http://www.fao.org/ag/agp/agpc/doc/counprof/uganda/uganda.htm). These two agro-ecological zones were selected for the study based on their distinct ecological features or conditions and their known history of cassava production in Uganda.

3.2 Source and description of cassava varieties

Three varieties, namely; Njule Red, Narocass1, and Nase 14, were used for the study. These varieties were selected based on their distinct leaf morphological characteristics. The planting materials for the respective varieties were sourced from low cassava mosaic and cassava brown streak disease pressure areas (Nwoya and Kabarole districts) and then visually assessed for the absence or presence of the two diseases. Only clean disease-free fields were used as source of materials.

Njule Red; It is a landrace, sweet in taste and predominantly grown in the central and western areas of Uganda. It has got long slender smooth leaves.

Narocass1; It is a recently released improved variety that is being promoted for its high yields and disease tolerance. It possesses broad smooth leaves.

Nase 14; It is an improved variety previously promoted for its high yield, drought and disease tolerance. It has broad hairy leaves.

3.3 Experimental Design and Management

The field experiments were laid out in a randomized complete block design (RCBD) with three replications and each experimental plot measuring 9m x 4m. Experimental plots were separated by 2m from each other while the replicates were separated by 3m. Each stake of 18cm – 25cm length with 3-5 nodes was planted at a spacing of 1m x 1m between plants and rows. Weeding was done using a hand hoe so as to avoid competition for resources.

3.4 Field Data Collection

Monthly data collection commenced at 3 MAP (months after planting) up to 8 MAP (months after planting). Data was collected on:

Serangium parcesetosum abundance: 10 plants were randomly selected from the trial plot. Each plant was then be observed from the top to bottom including all leaves (both the top and underside), petioles, the stem and a count of all *Serangium parcesetosum* larvae, adults were recorded as described by Asiimwe *et al*. (2007).

Whitefly Nymph population: 5 plants were selected randomly from the 10 plants assessed for the *Serangium parcesetosum* abundance and from each of the plants, a 14^{th} leaf (counting from top to bottom) was selected, harvested and placed in an Ziploc bag. The nymphs were then counted in the laboratory using a 10X magnifying hand lens. This was in accordance with the protocol published by Fishpool and Abisgold (1990).

Temperature and rainfall: Data on the average monthly maximum temperature (^{0}c) and total monthly rainfall (mm) was obtained from the metrological stations in Ngetta (Lira) and Kiige (Kamuli) for the period that the experiment was carried out.

3.5 Data Analysis

Mean *Serangium parcesetosum* populations were subjected to ANOVA followed by mean separations with least significance difference (LSD) at ($p \leq 0.05$) using XLSTAT 2016 statistical package. This was able to spell out the agro-ecological, varietal and age effect on the *Serangium parcesetosum* populations. Regression and correlation analysis tests were carried out to ascertain the relationship between the mean *Serangium parcesetosum adults* and larvae, their abundance and mean whitefly nymph population, as well as the influence of climatic factors on the predator population.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter collates the key results from the study in accordance to the specific objectives enlisted in the first chapter. It further points out the relevant discussions attached to the results.

4.1 Abundance of Serangium parcesetosum

Irrespective of location and variety, the average population per plant of *Serangium parcesetosum* larvae (6.23) was more abundant than the adults (2.68) (Figure 1). This could be attributed to the fact that the adults of *Serangium parcesetosum* are more mobile since they have wings and thus less likely to be observed during the data collection as compared to their counterparts, the larvae, that cover very short distances. Also, this trend could be explained by the high fecundity rate of the *Serangium parcesetosum.* This is supported by the work of Ahmad and Abboud (2001) which stated that a single female *Serangium parcesetosum* adult laid a mean of 443.9 eggs at 27 °C on a cassava plant infested with *Bemisia. tabaci*. This similar trend was further observed by Al-Zyoud *et al.* (2004). This means that the high number of eggs laid by a single female *Serangium parcesetosum* adult have more chances of developing into the larvae and thus explains the high population abundance compared to the adults that was recorded in this study.

Also, from this current study, a spearman`s correlation test was conducted between the mean adults and larvae *Serangium parcesetosum* population per plant. The test revealed a strong positive relationship ($r = 0.86$) between the two irrespective of the location (Appendix Figure 1). This revelation provides a strong basis for the use of either adults or larvae *Serangium parcesetosum* population as a single parameter in the quick field assessment of this predator population especially in circumstances of limited time and financial resources.

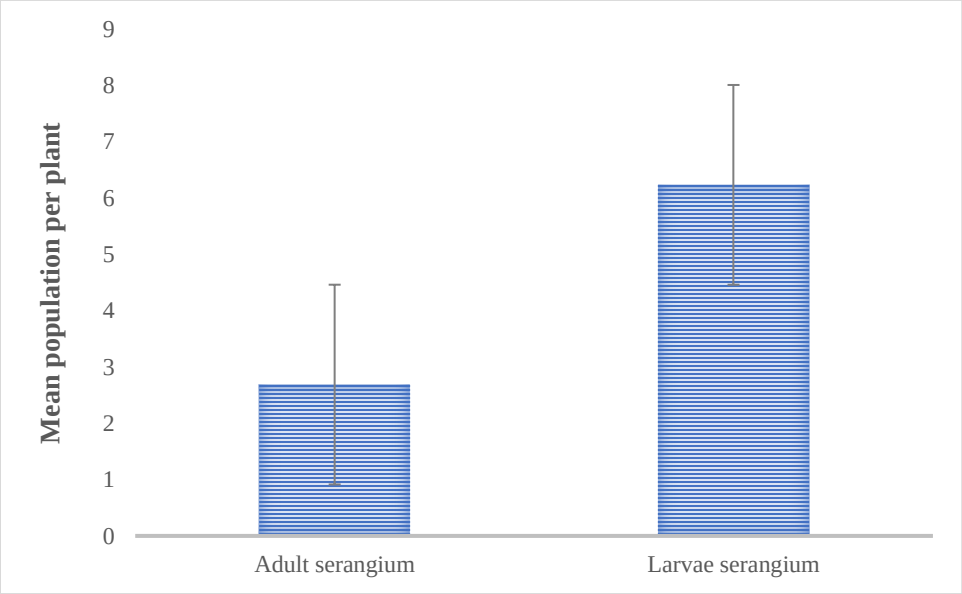

Figure 1: Mean adult and larvae *Serangium parcesetosum* populations per plant.

4.1.1 Effect of environment on *Serangium parcesetosum* abundance

Kamuli (4.92) registered higher mean population of *Serangium parcesetosum* adults per plant than Lira (0.39) (Figure 2). A similar trend was observed among the *Serangium parcesetosum* larvae where Lira recorded lower population (0.51) as compared to Kamuli (11.75) (Figure 3). Both *Serangium parcesetosum* adults ($p<0.0001$) and larvae ($p<0.0001$) varied significantly with the location (Appendix Table 1 and 2). This is due to the fact that Kamuli had a higher population of the whitefly nymphs compared to Lira (Table 1). This therefore depicts that the predator, *Serangium parcesetosum* preferred the location with more abundant prey. This variation in the abundance of the whitefly nymph population between the two locations can be explained by the different amounts of temperature and relative humidity experienced. The trial site in Kamuli is located near the banks of River Nile and this provides high temperature and relative humidity that favours high whitefly reproduction rate. Lira on the other hand experiences

high temperature but low relative humidity. The variation in whitefly nymph population can also be linked to the nature of the landscape of the two locations. The Kamuli landscape has been greatly disturbed by human settlement and agriculture compared to that of Lira which is moderately disturbed. This therefore leads to the migration of the whiteflies onto the cultivated cassava crop since its natural habitat have been destroyed. The reverse is true for Lira where the pest could still be confined to the natural habitat and thus less likely to colonize cassava crop. The observed results are in confirmation with research carried out by Al-Zyoud *et al*. (2004) which revealed that prey abundance, temperature, relative humidity and rainfall were the observed factors influencing the survivorship of *Serangium parcesetosum* on cotton. Legg *et al* (1994) also confirmed in his study that climatic factors like high temperature, relative humidity had a direct bearing on the population of whiteflies. He explained that the two factors resulted into faster development of the pest since the life cycle period had been greatly reduced. A study carried out by Grzegorz and Douglas (2012) further disclosed that the disturbance caused by urbanization negatively impacted on the abundance and diversity of ants. He explained that the disturbance created by urbanization destroys the habitat of a wide array of unique endemic species and so most of these pests then find their way to colonize the few crop gardens available.

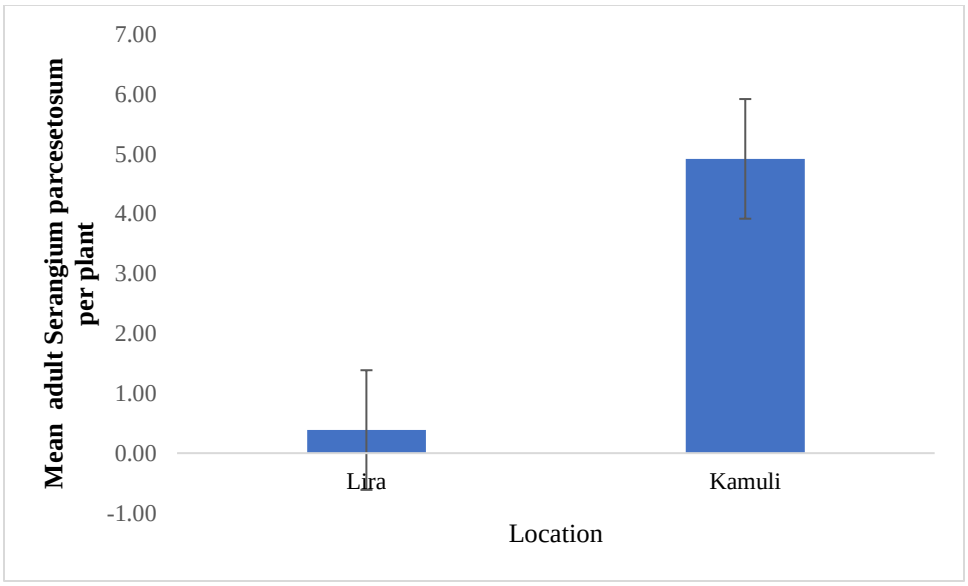

Figure 2: Mean adult *Serangium parcesetosum* population per plant across the two locations

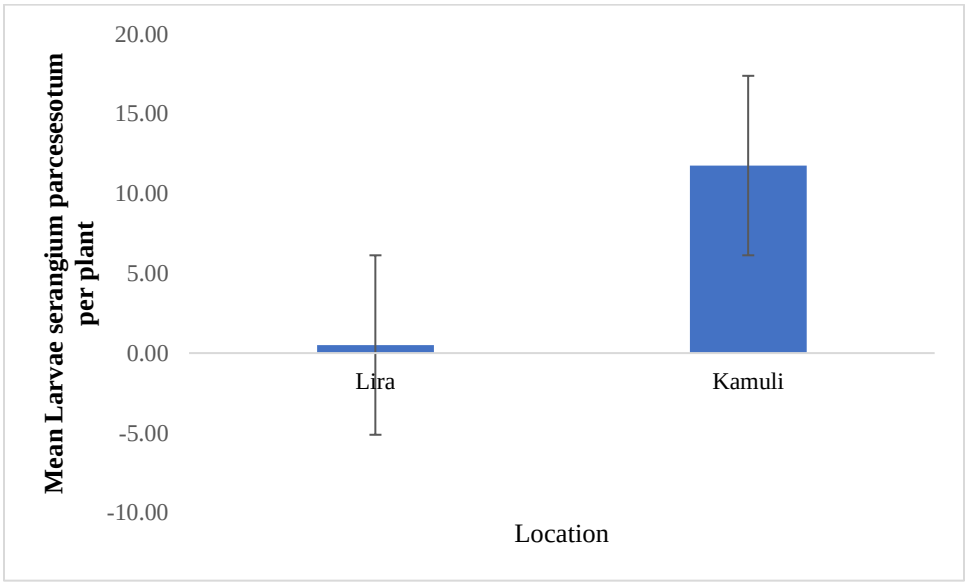

Figure 3: Mean larvae *Serangium parcesetosum* population per plant across the two locations

Location	Mean whitefly Nymphs counts per plant
Kamuli	223.32 ± 0.483
Lira	16.43 ± 0.321

Source: Data analysis

Table 1: Mean whitefly nymph counts per plant across the two locations

4.1.2 Effect of cassava variety on *Serangium parcesetosum* abundance

In Kamuli, improved broad-leafed cassava varieties; Narocass1 (4.88) and Nase 14 (5.74) were more preferred by the adult *Serangium parcesetosum* compared to Njule red (4.13), a slender long leafed landrace respectively. The same trend was observed in Lira where Njule red registered 0.23 adults per plant compared to Nase 14 (0.41) and Narocass1 (0.47) respectively (Figure 4). There was no significant difference (P < 0.489) in the adult *Serangium parcesetosum* population across the three varieties (Appendix 1).

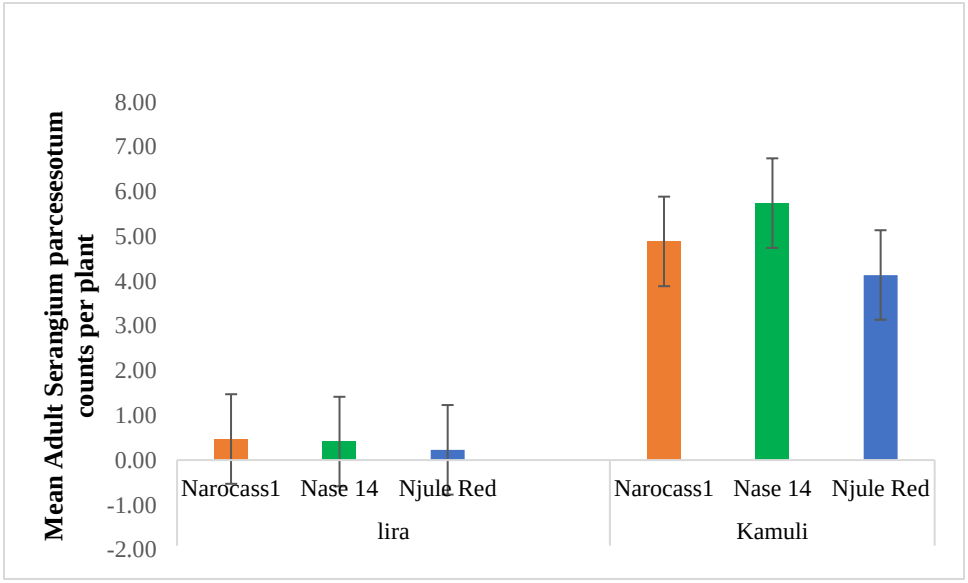

Figure 4: Mean adult *Serangium parcesetosum* counts per plant across varieties and locations

In Kamuli, Njule red (9.59), a slender long leafed landrace was still the least preferred by the *Serangium parcesetosum* larvae compared to the improved broad-leafed cassava varieties; Narocass1 (12.71) and Nase 14 (12.97) respectively. The trend was not any different in Lira where Nase 14 (0.62) and Narocass1 (0.63) registered higher *Serangium parcesetosum* larvae per plant as compared to Njule red (0.26) (Figure 5). The *Serangium parcesetosum* larvae per plant did not differ significantly ($P < 0.598$) with the cassava varieties (Appendix 1).

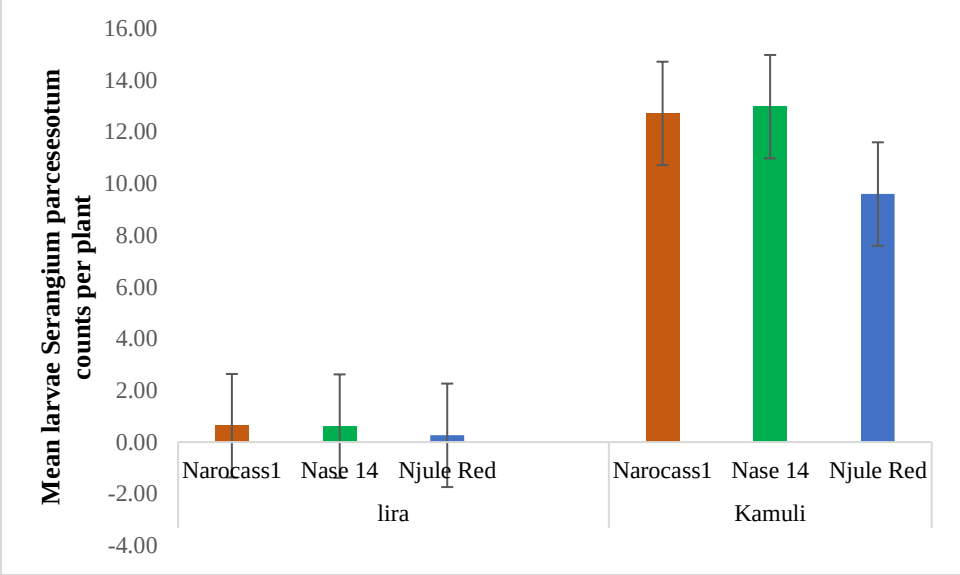

Figure 5: Mean *Serangium parcesetosum* larvae counts per plant across varieties and locations

Generally, the improved broad-leafed cassava varieties (Narocass1 and Nase 14) were more preferred by the *Serangium parcesetosum* adults and larvae compared to the long slender leafed landrace (Njule red) across both locations. The observed trend could be attributed to whitefly nymph population recorded on these varieties (Table 2). As observed in the study, improved broad-leafed cassava varieties; Narocass1 and Nase 14 had generally higher whitefly nymph population per plant compared to the landrace (Njule red). This variation in whitefly nymph population among the varieties could be brought about by the leaf shape and the surface area it

covers. Cassava varieties with broad or wide leaflets possibly offer a more sheltered micro climate to both the whiteflies and the predators and this provides a conducive environment for feeding and oviposition. The shelter is also known to reduce their natural mortality factors like wind, excessive sunshine and rainfall. This analogy is supported by the research carried out by Legg *et al*. (1994) which elucidated the influence of leaf morphology on the whitefly population. From this current study, it was observed that Nase 14, a hairy broad leafed improved cassava variety attracted the highest whitefly nymph population. This observation is confirmed by Ramazan and Heather (2009) whose research concluded that the hairy broad-leafed cotton cultivars attracted more whitefly populations compared to the smooth slender leafed ones. This was due to the increased whitefly oviposition.

Cassava variety	**Mean whitefly nymph population per plant**	
	Kamuli	**Lira**
Narocass1	237.3 ± 17.53	15.08 ± 2.85
Nase 14	273.4 ± 12.42	18.83 ± 2.77
Njule red	159.6 ± 8.34	14.13 ± 2.85

Source: Data Analysis

Table 2: Mean whitefly nymph population per plant among cassava varieties across location

4.1.3 Effect of cassava age on *Serangium parcesetosum* abundance

In Lira, the adult *Serangium parcesetosum* population commenced at 3 MAP registering 0.19 individuals per plant before having a steady increment at 4 MAP (0.22) and 5 MAP (0.25). The population then rose steeply reaching the peak at 6 MAP (0.90) before drastically declining at 7 MAP (0.32) and 8 MAP (0.35) respectively (Figure 6). In Kamuli, the adult *Serangium parcesetosum* population followed a slightly different trend. At 3 MAP, the population started at

a low note (0.84) and then gradually increased at 4 MAP (1.84) before drastically increasing at 5 MAP (6.47) before peaking at 6 MAP (8.72). The population then dropped tremendously up to 7 MAP (4.05) followed by a sudden rise at 8 MAP (7.58) (Figure 7).

The mean *Serangium parcesetosum* larvae population in Lira followed a very similar trend as that observed among the mean adult *Serangium parcesetosum* population (Figure 6). However, there was a slight difference in the abundance levels as the larvae registered high numbers compared to the adults. In Kamuli, the trend was slightly different compared to that of the mean adult *Serangium parcesetosum* population. The mean *Serangium parcesetosum* larvae population kicked off at 3 MAP with 2.39 individuals per plant before it declined at 4 MAP (0.41). This was followed by a very sharp increase to the peak at 5 MAP (22.48) and thereafter a deceleration at 6 MAP (19.71) and 7 MAP (11.08) before another increment at 8 MAP (14.46) (Figure 7).

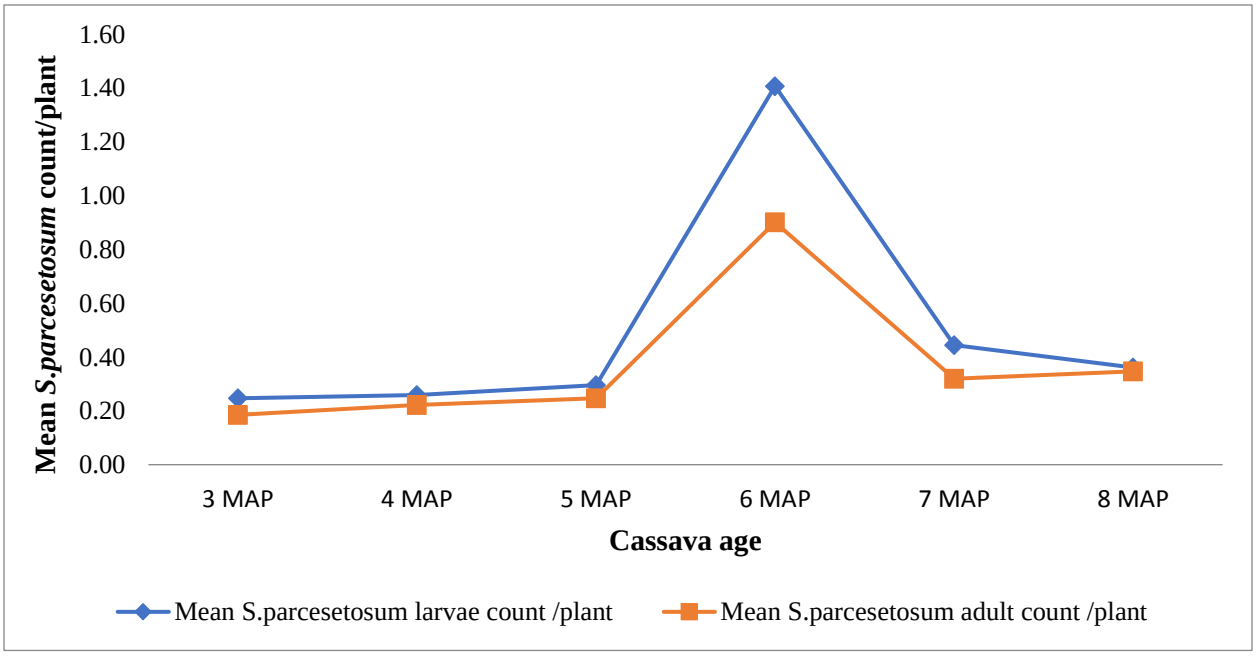

Figure 6: Changes in mean *Serangium parcesetosum* population per plant with cassava age in Lira

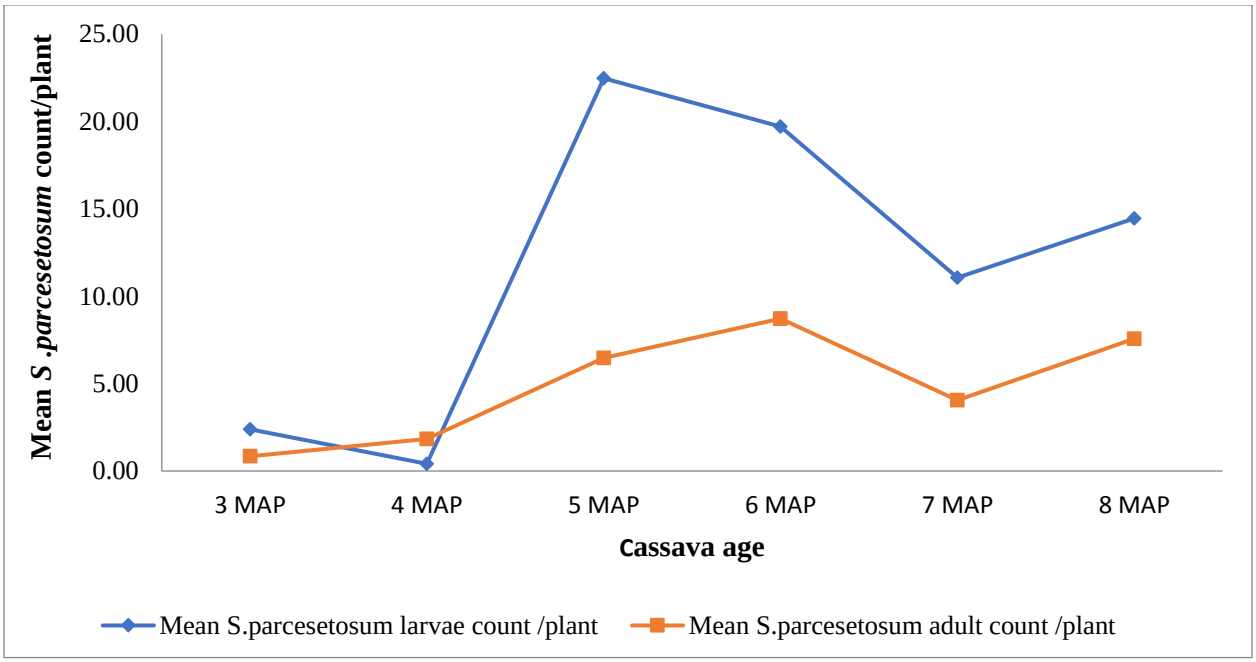

Figure 7: Changes in mean *Serangium parcesetosum* population per plant with cassava age in Kamuli

The observed trend of the changes in the mean *Serangium parcesetosum* population per plant with the cassava age could be attributed to the mean whitely nymph population recorded. (Leuschner, 1978; Dengel, 1981; Fishpool *et al*. 1995) and, Ramazan and Heather (2009) all observed in their respective researches that whitefly population peaked between 3 MAP and 6 MAP before declining more or less rapidly to a lower level for the remainder of the cassava crop life. They explained that in the early months, the pest is just beginning to colonize the crop but later builds up from 3 MAP to 6 MAP. The decline thereafter was however attributed to crop maturity since the plant then diverts the photosynthates to tuberisation and thus rendering the remaining aerial parts unpalatable for feeding by the whitefly.

From this current study, it was observed that the peaks of both mean adult and larvae *Serangium parcesetosum* at 6 MAP in Lira coincided with relatively high nymph population at the same MAP within the same locality (Appendix 6). The predator population then reduced with the declining whitefly nymph population. The same trend was observed in Kamuli only that both mean adult and larvae *Serangium parcesetosum* peaked at an earlier month before decelerating with the reduction in whitefly nymph population (Appendix Figure 10). These observations suggest that whitefly nymph population recorded as per respective ages of the cassava could explain their varying population of adult and larvae *Serangium parcesetosum* though the trend is not clear.

4.2 Field relationship between Serangium parcesetosum and its prey, the whitefly

A linear regression test was carried out between both the mean *Serangium parcesetosum* larvae and adults and the average whitefly nymph counts per plant respectively. Irrespective of location, 27% and 30% increment in the mean adult and larvae *Serangium parcesetosum* population per plant respectively was registered (Figure 8 and 9). This was attributed to the mean whitefly nymph population per plant registered in the field. Like earlier discussed in the results of objective one, the abundance of both adult and larvae *Serangium parcesetosum* are greatly influenced by the availability of their prey, the whitefly nymphs. This appears to be the main factor affecting their population. This is attributed to the fact that the *Serangium parcesetosum* will rapidly increase in population owing to the faster reproduction as a result of sufficient amounts of nutrients provided by the whitefly nymphs. This is supported by the great research works of Legg *et al*. (1994) and Al-Zyoud *et al.* (2004) who highlighted that prey abundance and climatic factors were the profound drivers of *Serangium parcesetosum* populations.

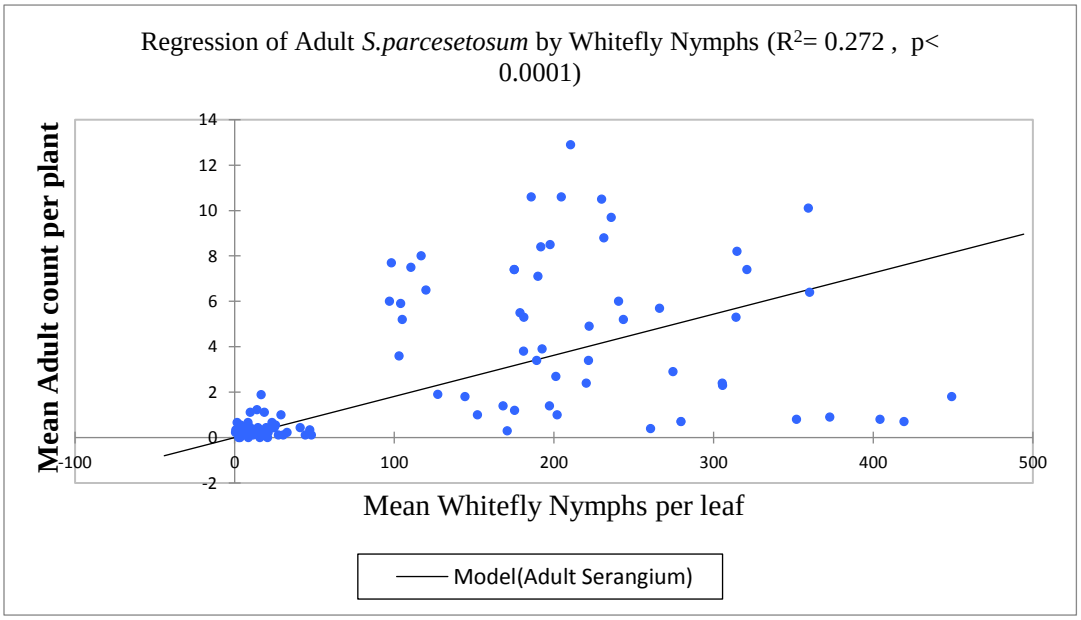

Figure 8: Regression of Mean adult *Serangium parcesetosum* by mean whitefly nymph counts per plant

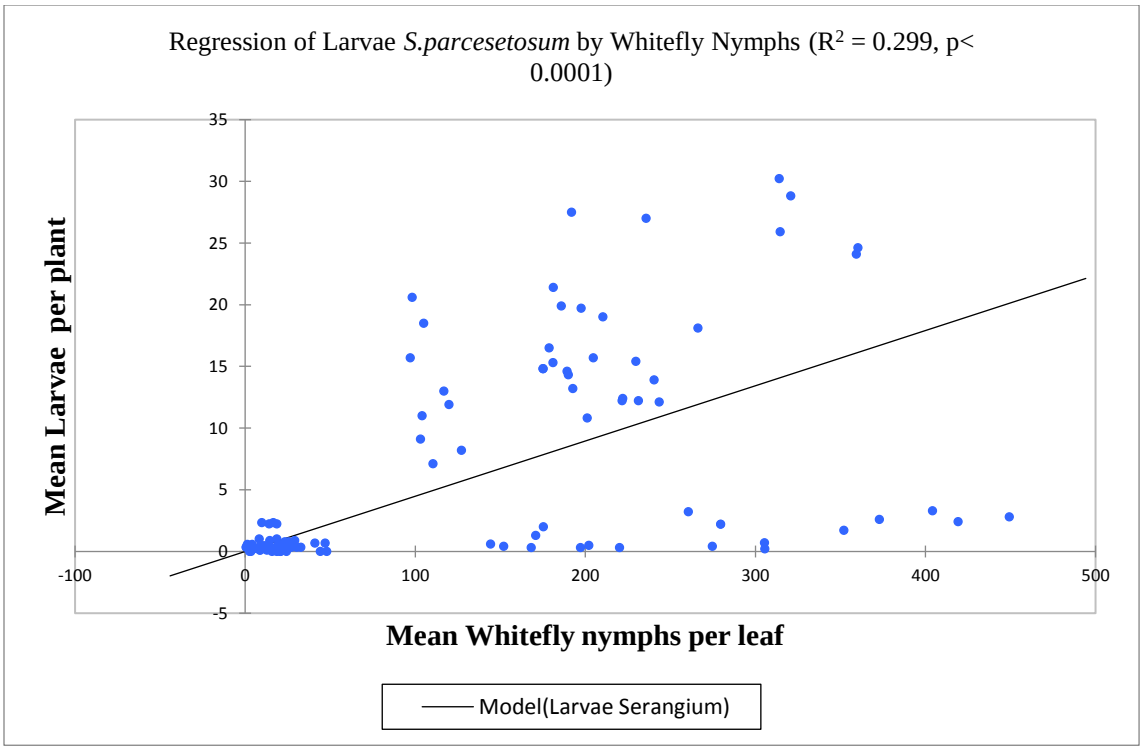

Figure 9: Regression of Mean larvae *Serangium parcesetosum* by Mean whitefly Nymph counts per plant

4.3 Influence of climatic factors on *Serangium parcesetosum* population

4.3.1 Influence of temperature on the abundance of *Serangium parcesetosum*

In Lira, the mean adult *Serangium parcesetosum* population began at a low note (0.2 individuals /plant) at the highest average maximum temperature of 30.2 ^{0}c (3 MAP) and steadily increased up to the peak with 0.9 individuals per plant at a temperature of 29.3^{0}c (6 MAP) before declining up to 0.3 adults at a temperature of 29.9^{0}c (8 MAP) (Figure 10). A similar trend was observed with the mean *Serangium parcesetosum* larvae population in the same location (Figure 11).

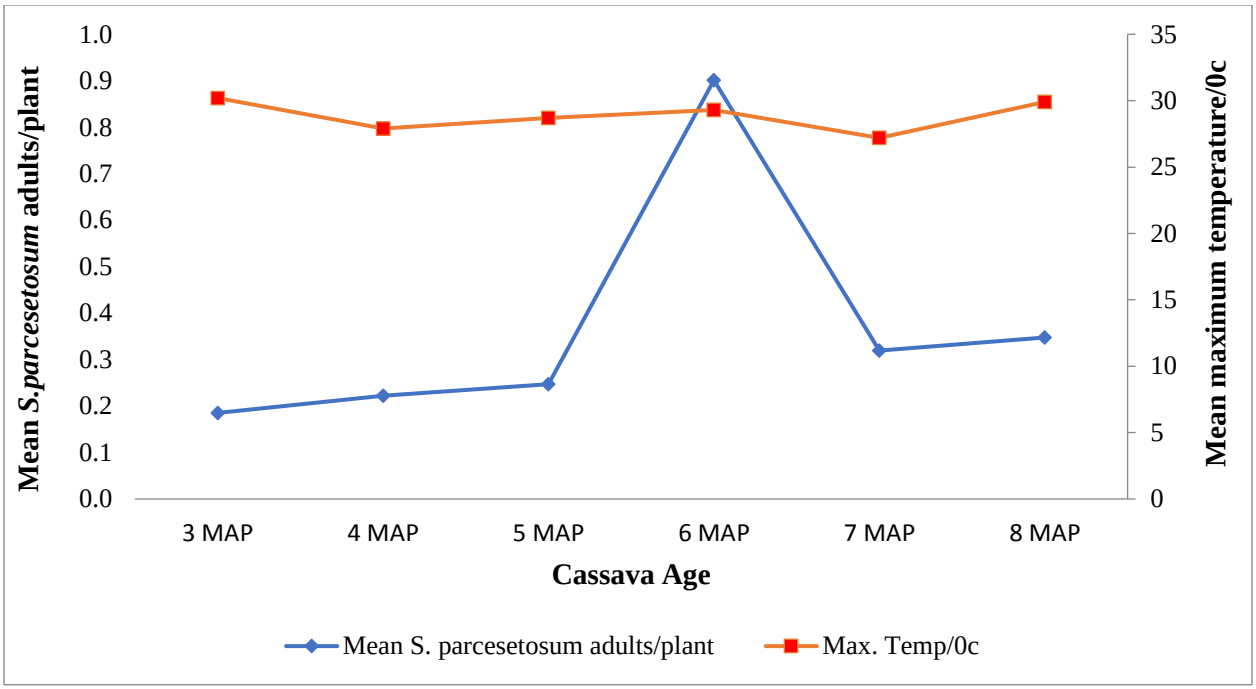

Figure 10: Influence of maximum monthly average temperature on the *Serangium parcesetosum* adults population in Lira

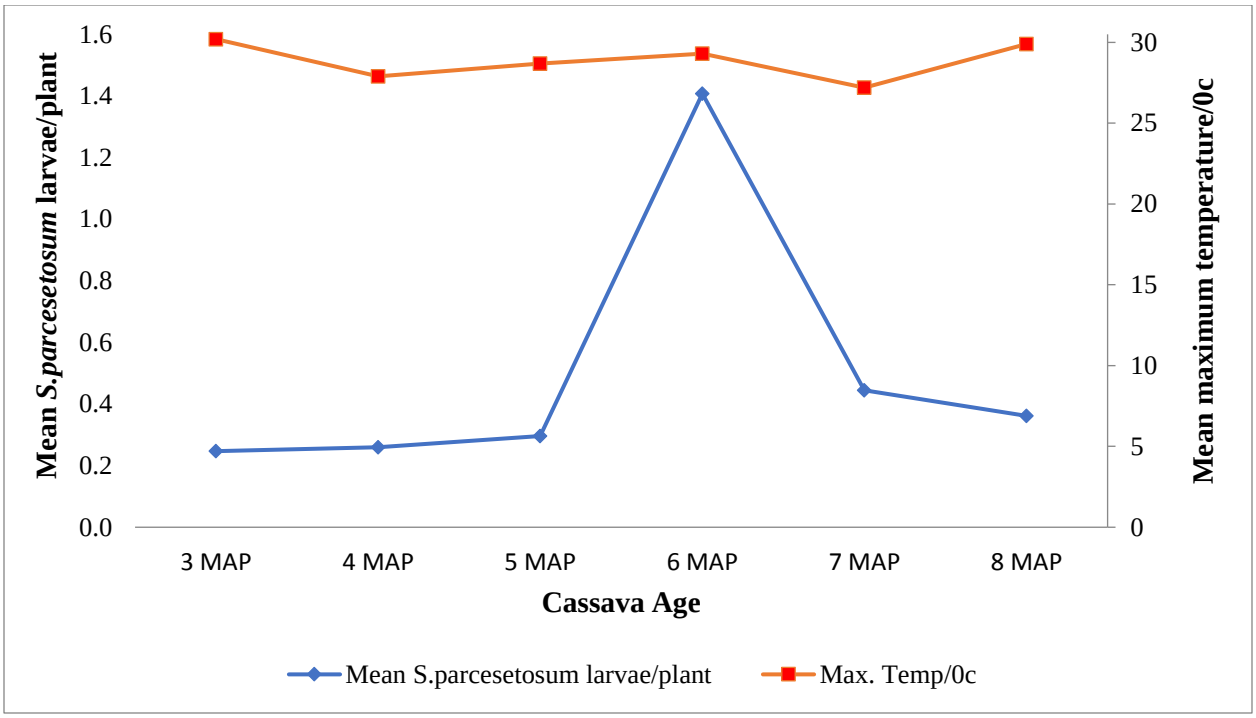

Figure 11: Influence of maximum monthly average temperature on the *Serangium parcesetosum* larvae population in Lira

A linear regression test was carried out between both the mean *Serangium parcesetosum* larvae and adults per plant and the average maximum monthly temperature in Lira. 1.1 % ($p< 0.845$) and 1.8 % ($p<0.801$) increment in the mean adult and larvae *Serangium parcesetosum* population per plant respectively was registered (Appendix 4). This was attributed to the mean maximum monthly temperature recorded in the field.

In Kamuli, the mean adult *Serangium parcesetosum* population started low (0.8 individuals /plant) at a low average maximum temperature of 24.0 ^{0}c (3 MAP) and drastically increased up to the peak with 8.7 individuals per plant at a temperature of 25.0^{0}c (6 MAP) before declining up to 4.1 adults at a temperature of 29.5^{0}c (7 MAP). The population thereafter increased to 7.6 adults per plant at 28.5^{0}c (8 MAP) (Figure 12). Generally, a similar trend was observed with the mean *Serangium parcesetosum* larvae population but, a slight variation was observed in the

peaking. The mean *Serangium parcesetosum* larvae population peaked at 5 MAP with 22.5 mean larvae per plant at a temperature of 24.2^0c (Figure 13).

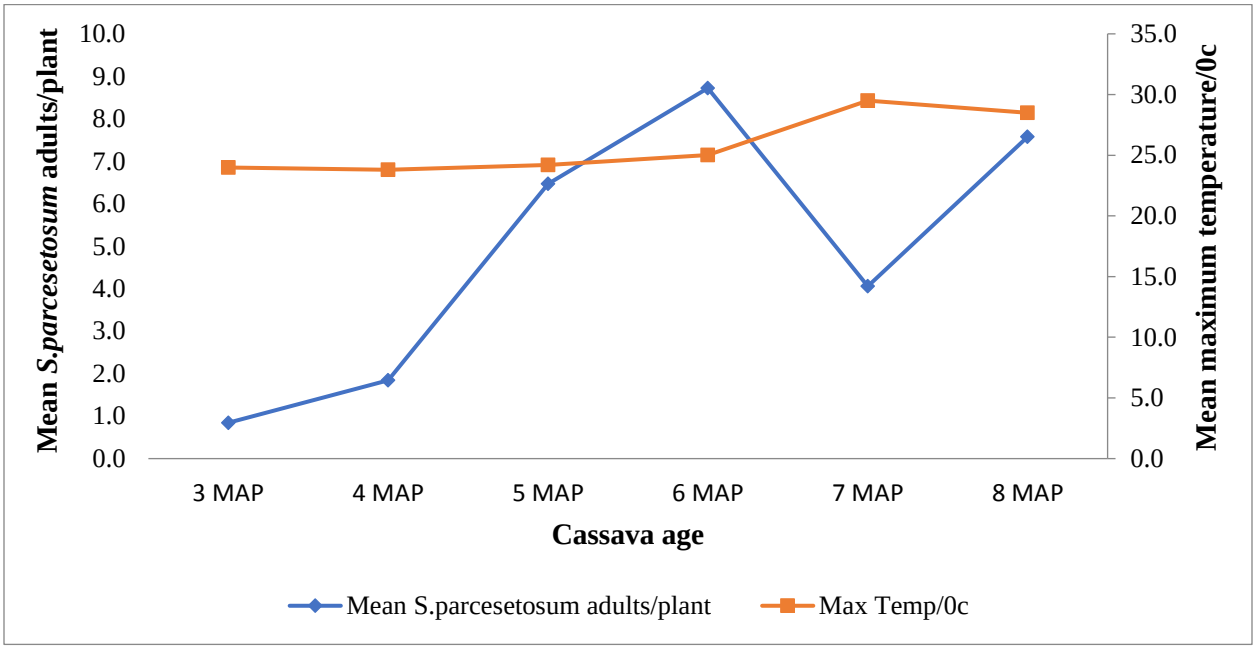

Figure 12: Influence of maximum monthly average temperature on the *Serangium parcesetosum* adult population in Kamuli

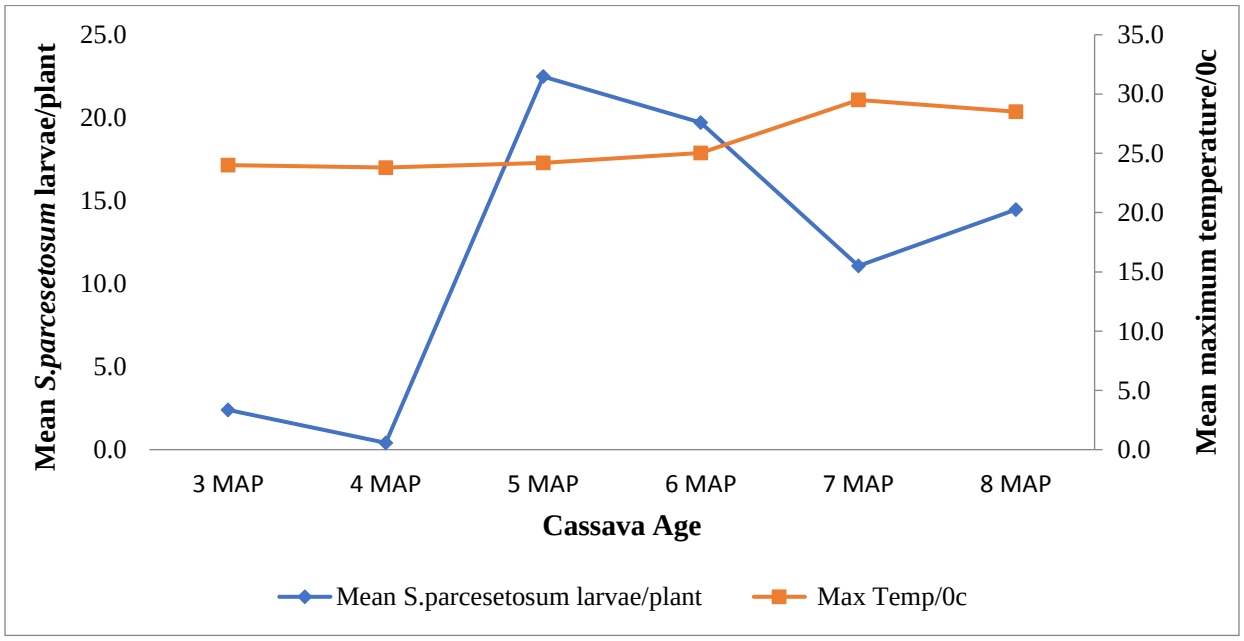

Figure 13: Influence of maximum monthly average temperature on the *Serangium parcesetosum* larvae population in Kamuli

Also, after carrying out a linear regression test between both the mean *Serangium parcesetosum* larvae and adults per plant and the average maximum monthly temperature in Kamuli, 3.5% ($p< 0.724$) and 9.1% ($p< 0.561$) increment in the mean adult and larvae *Serangium parcesetosum* population per plant respectively was associated with the mean maximum monthly temperature recorded in the field (Appendix 4).

The results suggest that maximum temperature has a slight effect on the larvae and adult *Serangium parcesetosum* population in the two locations. This literally means that the predator population increased with an increment in maximum temperature. Like discussed earlier on, higher temperature increases the development period of both the whitefly and its predator, *Serangium parcesetosum* and thus increases their population in a very short period of time. This school of thought is supported by research done by Dengel (1981) and Legg (1994). However, the small increment in the predator population as a result of temperature observed in the study could have been influenced by many other factors interacting in the field and thus reduced its impact.

4.3.2 Influence of rainfall on the abundance of *Serangium parcesetosum*

Kamuli registered a low mean adult *Serangium parcesetosum* population at the start (0.8 individuals /plant) with a low total monthly rainfall of 52.4mm (3 MAP) and gently increased up to the peak (8.7 individuals per plant) with moderate rainfall of 138mm (6 MAP). The adult population then declined up to 4.1 adults with highest rainfall of 361.7 mm (7 MAP) and thereafter increased to 7.6 adults per plant with 81.3mm of rainfall (8 MAP) (Figure 14). Still, a similar trend was generally observed with the mean *Serangium parcesetosum* larvae population though a slight variation was observed in the peaking. The mean *Serangium parcesetosum* larvae

population peaked at 5 MAP (22.5 mean larvae per plant) with the lowest total monthly rainfall of 46.4 mm (Figure 15).

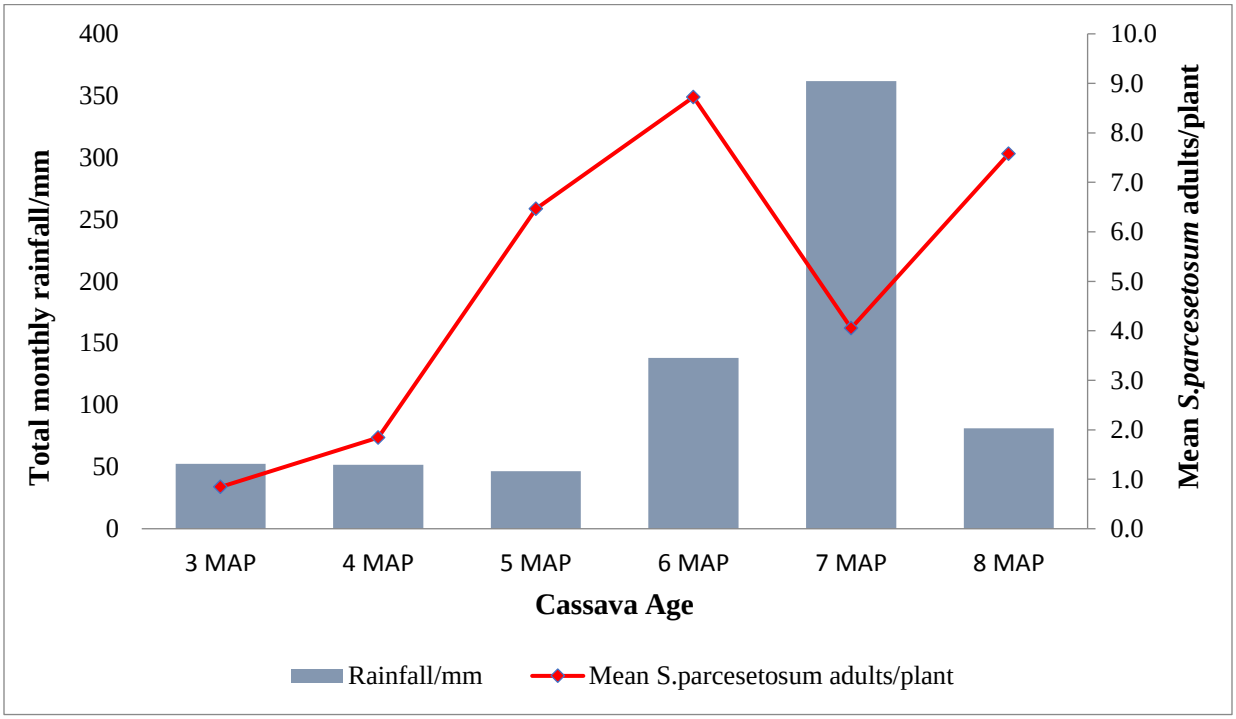

Figure 14: Changes of total monthly rainfall with the *Serangium parcesetosum* adults population over time in Kamuli

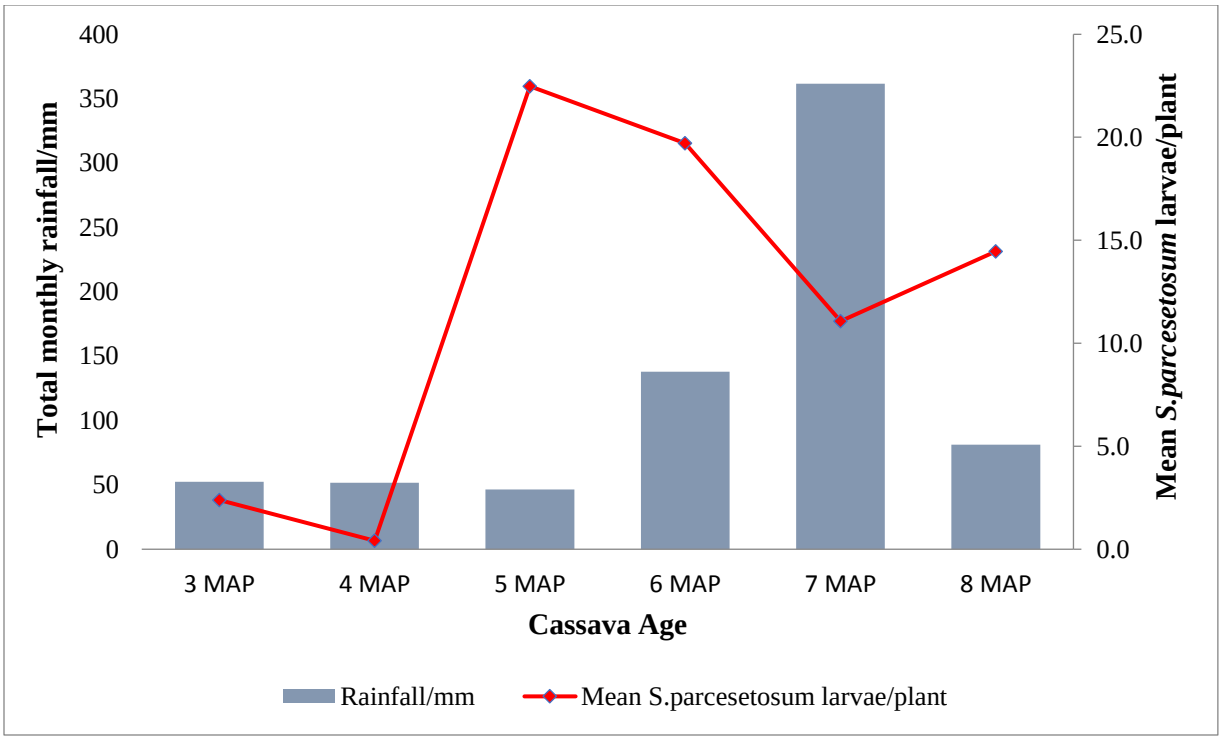

Figure 15: Changes of total monthly rainfall with the *Serangium parcesetosum* larvae population over time in Kamuli

In order to understand the relationship between the total monthly rainfall and mean *Serangium parcesetosum* larvae and adults per plant, a linear regression was carried out. 0.8% ($p < 0.865$) and 0.4% ($p < 0.901$) increment in the mean larvae and adult *Serangium parcesetosum* population per plant respectively was associated with the total monthly rainfall recorded in the field (Appendix 5).

In Lira, the mean adult *Serangium parcesetosum* population began with a low population (0.2 individuals /plant) with the highest total monthly rainfall of 174.3mm (3 MAP) and steadily increased up to the peak with 0.9 individuals per plant with rainfall of 165.7mm (6 MAP) before declining up to 0.3 adults with 155.7mm of rainfall (8 MAP) (Figure 16). A similar trend was observed with the mean *Serangium parcesetosum* larvae population in the same location (Figure 17).

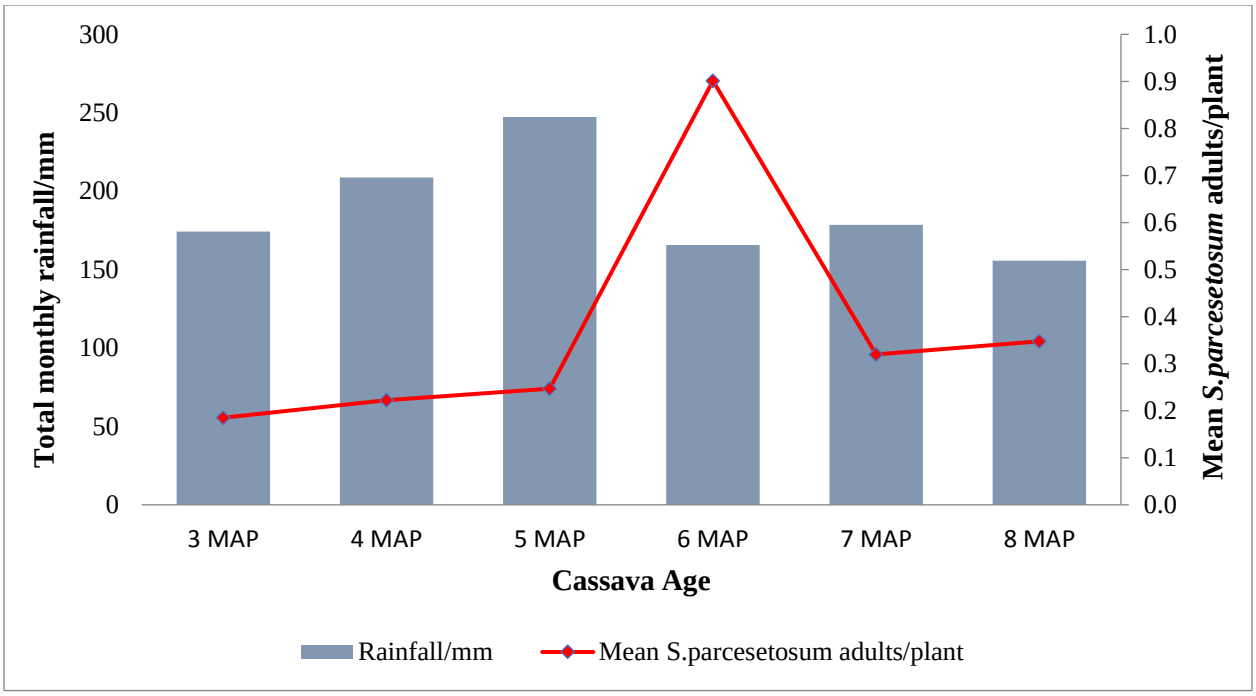

Figure 16: Changes of total monthly rainfall with the *Serangium parcesetosum* adults population over time in Lira

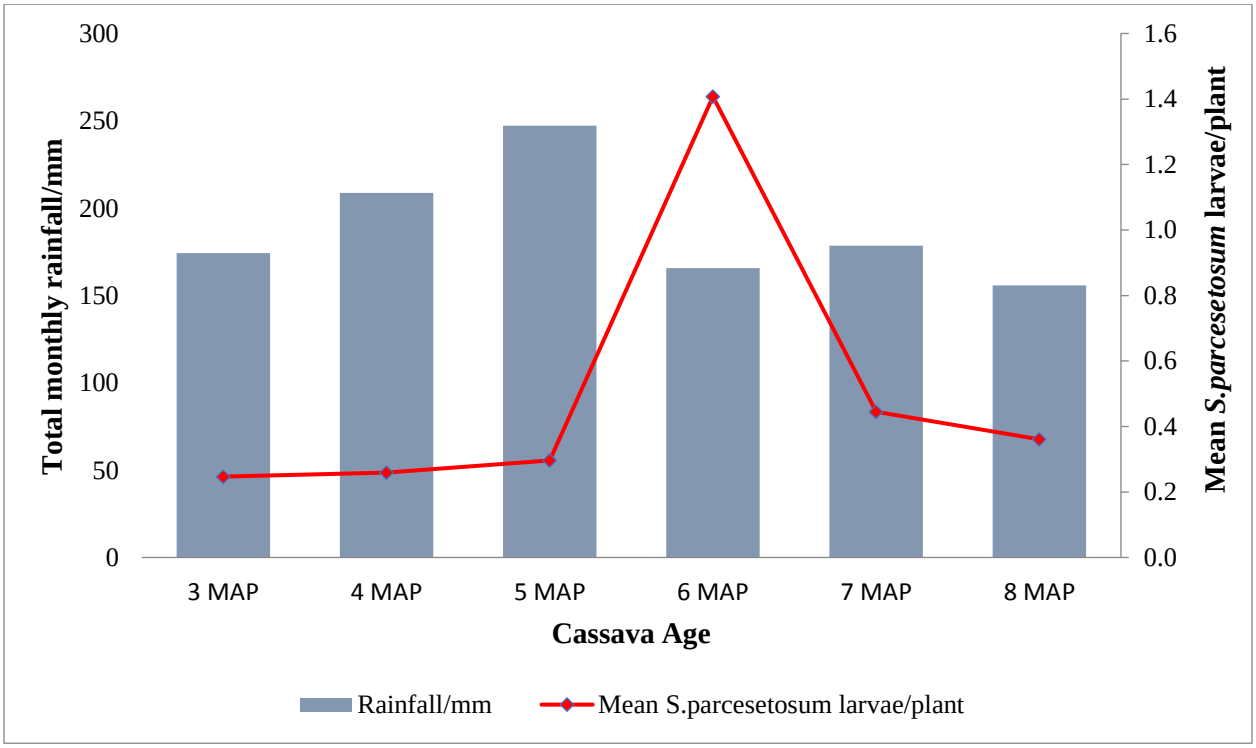

Figure 17: Changes of total monthly rainfall with the *Serangium parcesetosum* larvae population over time in Lira

A linear regression test was carried out between both the mean *Serangium parcesetosum* larvae and adults per plant and the total monthly rainfall received in Lira. 14.3 % ($p< 0.460$) and 16.6 % ($p<0.422$) decrease in the mean adult and larvae *Serangium parcesetosum* population per plant respectively was registered (Appendix 5). This was also attributed to the total monthly rainfall recorded in the field.

These observations also indicate that rainfall has a minimal effect on the larvae and adult *Serangium parcesetosum* population in the two locations. This actually means that the predator population increased with an increment in total monthly rainfall in Kamuli while a reverse trend was registered in Lira. According to Fishpool *et al*. (1995), and Legg (1994), the observed reduction in whitefly adults after a heavy rainfall shower can be inferred to the mechanical action done by the heavy rains that destroys the adults and thus reduces the eventual oviposition. This could explain the reduction of the whitefly predator *Serangium parcesetosum* population in Lira. Dengel (1981) on the other hand, registered a high whitefly population during the rainy season and attributed it to the occurrence of the new leaf flushes that attract the whiteflies because they are palatable for feeding. This could explain the trend of increment *Serangium parcesetosum* population in Kamuli. The minor increment and decrease in the predator population in the two locations as a result of rainfall, could have been influenced by many other factors interacting in the field and thus reduced its impact.

CHAPTER FIVE

SUMMARY OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter combines the summary of the key results, conclusions as well as the practical recommendations that this study provides to the relevant stakeholders.

5.1 Summary of results

Results of this study show that;

- *Serangium parcesetosum* is a naturally occurring predator among cassava fields in Uganda and it colonizes the cassava plant to feed on whiteflies (*Bemisia tabaci*).
- Both adult and larvae of *Serangium parcesetosum* were more abundant in the Kyoga plains (Kamuli) compared to the Northwestern savannah grassland (Lira) among the broad based improved varieties (Nase 14 and Narocass1) than the long slender landrace (Njule red).
- The main factor influencing this differential distribution of the predator is the abundance of its prey (*Bemisia tabaci*).
- *Serangium parcesetosum* population in both locations peaked at 5 to 6 months after planting which also coincides with the known similar period for the whiteflies peaking on cassava.
- A positive relationship was registered between both adult and larvae of *Serangium parcesesotum* and their prey, the whitefly nymphs. This means that the whitefly nymph population per plant bore a moderate increasing effect on *Serangium parcesesotum* population per plant.

- The research study also explained that maximum monthly temperature (^{0}c) had a minimal increasing effect on both the adult and larvae *Serangium parcesesotum* population per plant in both locations. To the contrary, the total monthly rainfall (mm) registered a decreasing effect on the predator population in Northwestern savannah grassland (Lira) while the reverse was true in Kyoga plains (Kamuli). However, in both locations, the influence of rainfall was still negligible.

5.2 Conclusions

This study established that location and cassava age were drivers of whitefly population which directly influenced the population of adult and larvae *Serangium parcesetosum*. This information is crucial towards the development of biological control options for cassava whitefly. However, there is need to expand this research to other agroecological zones for validation before it can be recommended for application in Uganda.

5.3 Recommendations from the study

Since the study established a strong positive correlation between adult and larvae of *Serangium parcesetosum* observed in the different locations, the researchers are urged to use either adults or larvae in the estimation of *Serangium parcesesotum* population in the field especially in situation of financial and time limitations.

The research study also urges the entomologists and other scientists who intend to augment the predator (*Serangium parcesetosum*) in control of cassava whiteflies to deploy broad leafed improved varieties like Nase 14 and Narocass 1 since they consistently attracted more predator

populations. In face of this, a more detailed and rigorous study is imminent to screen a larger population of cassava genotypes to assess their preference by *Serangium parcesetosum*.

The study calls for efforts to carry out genetic diversity studies using molecular tools (next generation sequencing) to elucidate the genetic relationship between the *Serangium parcesetosum* that are colonizing cassava in different agroecological zones in Uganda.

A detailed screen house study is also recommended for the measurement of the actual contribution of climatic factors in the *Serangium parcesetosum* population build up in Uganda.

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APPENDICES

Appendix 1: ANOVA of *S. parcesetosum* and whitefly nymphs population

Source	DF	Sum of squares	Mean squares	F	Pr > F
Age	5	8.231	1.646	46.390	< **0.0001**
Location	1	27.189	27.189	766.233	< **0.0001**
Genotype	2	0.051	0.026	0.721	0.489
Age*Location	5	1.899	0.380	10.705	< **0.0001**
Age*Genotype	10	0.587	0.059	1.655	0.108
Location*Genotype	2	0.112	0.056	1.571	0.215

Analysis of variance of mean adult *Serangium parcesetosum* per plant

Source	DF	Sum of squares	Mean squares	F	Pr > F
Age	5	12.908	2.582	110.707	< **0.0001**
Location	1	30.619	30.619	1313.080	< **0.0001**
Genotype	2	0.024	0.012	0.517	0.598
Age*Location	5	12.696	2.539	108.897	< **0.0001**
Age*Genotype	10	0.665	0.066	2.851	**0.005**
Location*Genotype	2	0.038	0.019	0.815	0.447

Analysis of variance of mean *Serangium parcesetosum* larvae per plant

Source	DF	Sum of squares	Mean squares	F	Pr > F
Age	5	3.659	0.732	33.879	< **0.0001**
Location	1	41.404	41.404	1916.590	< **0.0001**
Genotype	2	0.577	0.289	13.356	< **0.0001**
Age*Location	5	3.136	0.627	29.037	< **0.0001**
Age*Genotype	10	0.326	0.033	1.508	0.152
Location*Genotype	2	0.161	0.081	3.734	**0.028**

Analysis of variance of mean whitefly nymphs per leaf

Appendix 2: Analysis of differences in *S. parcesetosum* and whitefly nymphs population

Category	LS means	Standard error	Lower bound (95%)	Upper bound (95%)	Groups	
Lira	0.386	0.065	0.257	0.515	A	
Kamuli	4.919	0.170	4.580	5.257		B

Analysis of the differences between mean adult *Serangium parcesetosum* per plant across location using Tukey HSD at 95% confidence interval

Category	LS means	Standard error	Lower bound (95%)	Upper bound (95%)	Groups	
Lira	0.505	0.175	0.157	0.853	A	
Kamuli	11.754	0.291	11.174	12.334		B

Analysis of the differences between mean larvae *Serangium parcesetosum* per plant across location using Tukey HSD at 95% confidence interval

Category	LS means	Standard error	Lower bound (95%)	Upper bound (95%)	Groups	
Lira	16.085	2.908	10.298	21.871	A	
Kamuli	223.322	5.176	213.022	233.622		B

Analysis of the differences between mean whitefly nymphs per leaf across location using Tukey HSD at 95% confidence interval

Category	LS means	Standard error	Lower bound (95%)	Upper bound (95%)	Groups				
3 MAP	0.515	0.118	0.279	0.750	A				
4 MAP	1.033	0.088	0.858	1.209		B			
7 MAP	2.220	0.338	1.547	2.893			C		
5 MAP	3.357	0.206	2.946	3.767			C	D	
8 MAP	3.977	0.150	3.679	4.276				D	E
6 MAP	4.812	0.367	4.082	5.542					E

Analysis of the differences between mean adult *Serangium parcesetosum* per plant across the cassava age using Tukey HSD at 95% confidence interval

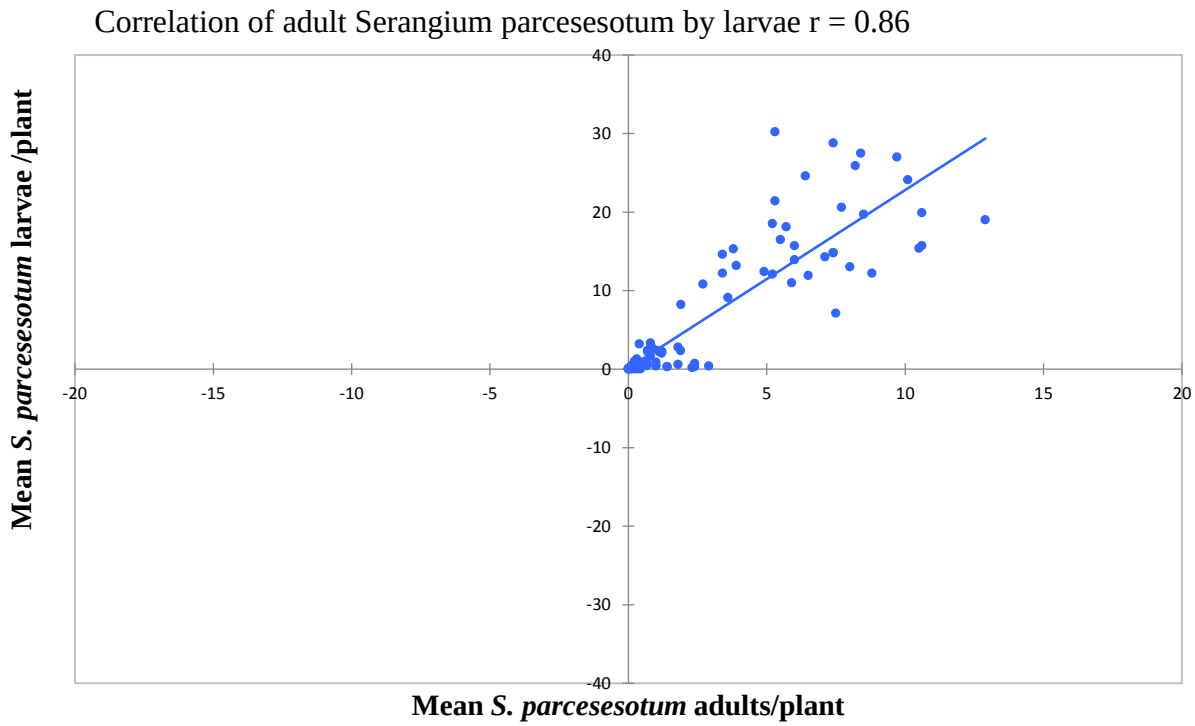
Category	LS means	Standard error	Lower bound (95%)	Upper bound (95%)	Groups				
3 MAP	0.335	0.257	-0.177	0.848	A				
4 MAP	1.318	0.202	0.917	1.719		B			
5 MAP	5.722	0.189	5.346	6.098			C		
6 MAP	7.454	0.378	6.703	8.205				D	
7 MAP	10.559	0.456	9.651	11.467					E
8 MAP	11.387	0.685	10.023	12.751					E

Analysis of the differences between mean *Serangium parcesetosum* larvae per plant across the cassava age using Tukey HSD at 95% confidence interval

Category	LS means	Standard error	Lower bound (95%)	Upper bound (95%)	Groups			
3 MAP	84.519	1.538	81.458	87.580	A			
4 MAP	95.817	2.661	90.521	101.112		B		
5 MAP	96.969	3.293	90.416	103.523		B		
6 MAP	125.555	11.498	102.673	148.437		B	C	
7 MAP	145.325	4.287	136.794	153.856			C	
8 MAP	170.036	11.400	147.349	192.723			C	

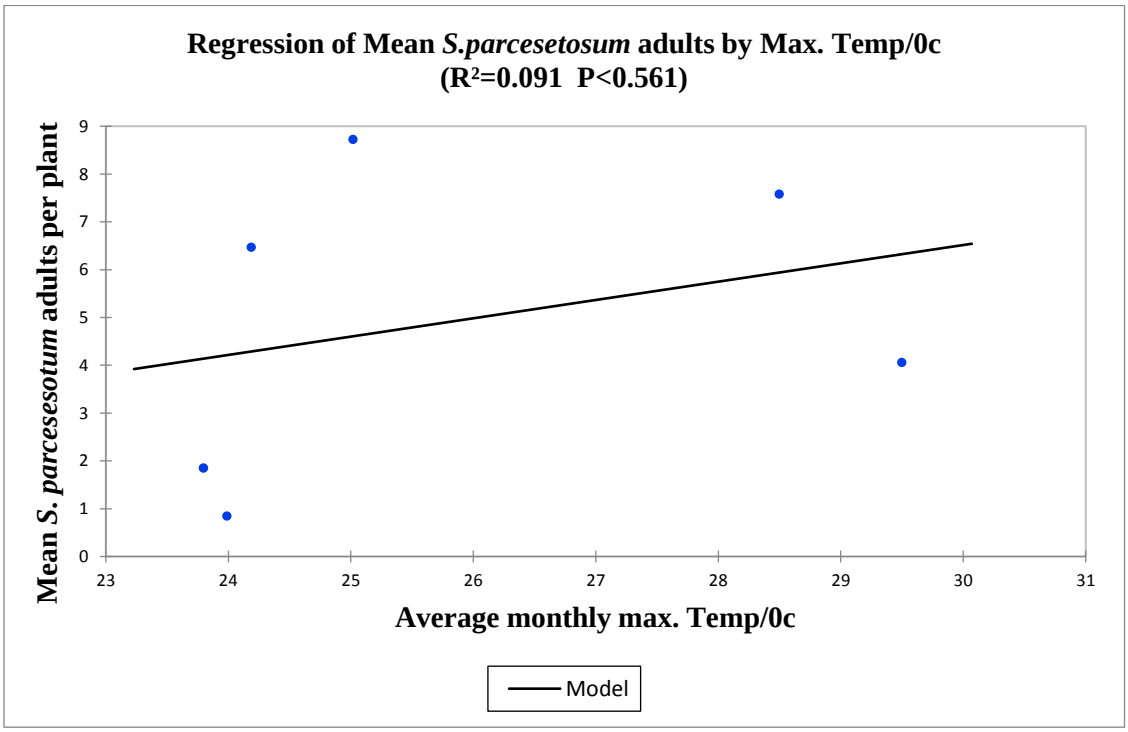
Analysis of the differences between the mean whitefly nymph per leaf across the cassava age using Tukey HSD at 95% confidence interval

Appendix 3: **Correlation of adult and larvae *S. parcesetosum* population**

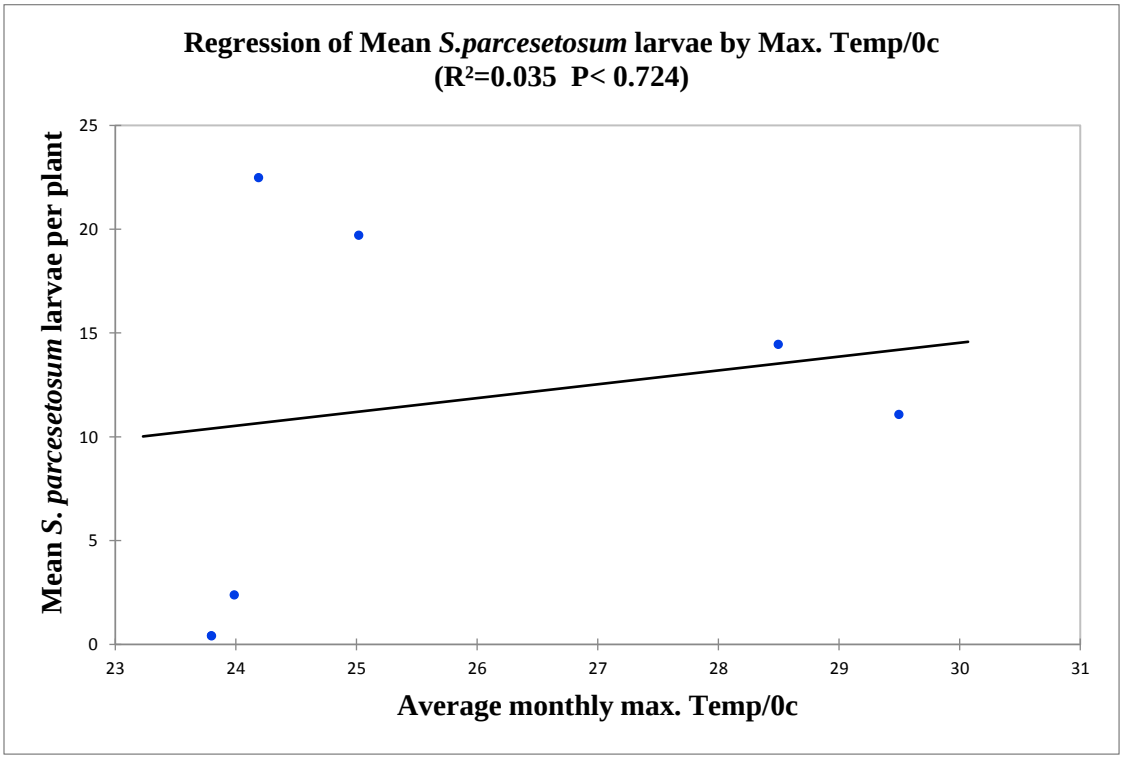


Correlation of mean adult *Serangium parcesetosum* by larvae

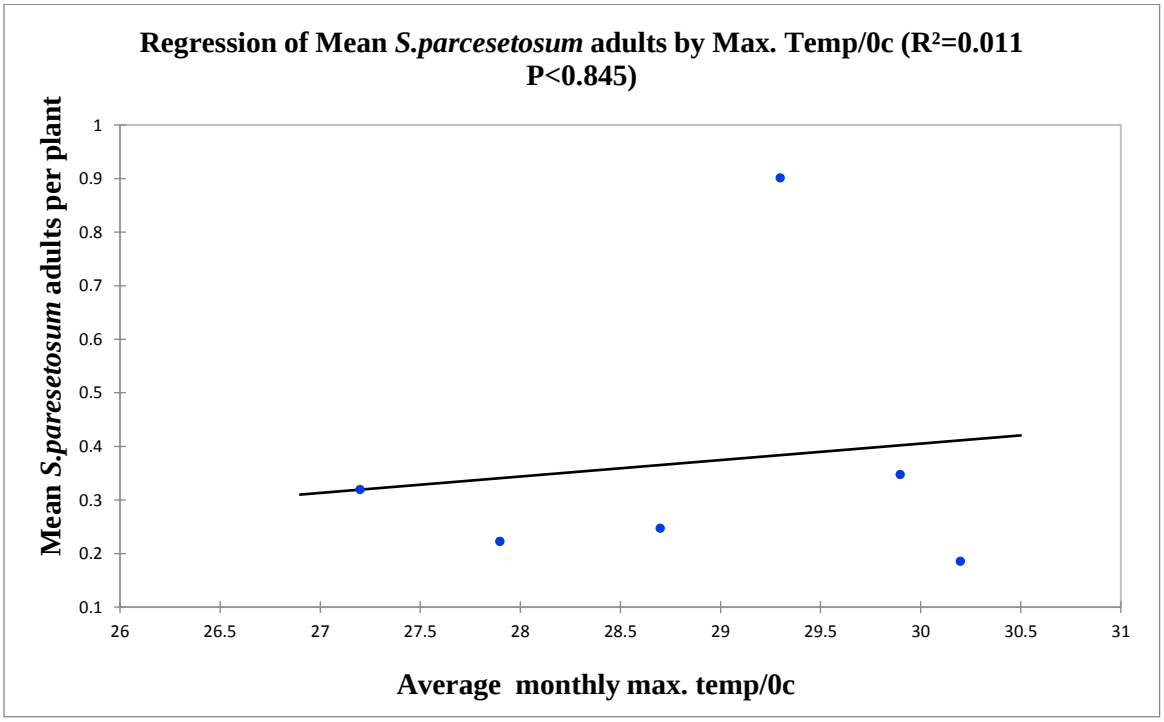
Appendix 4: Regression of *S. parcesetosum* population by temperature



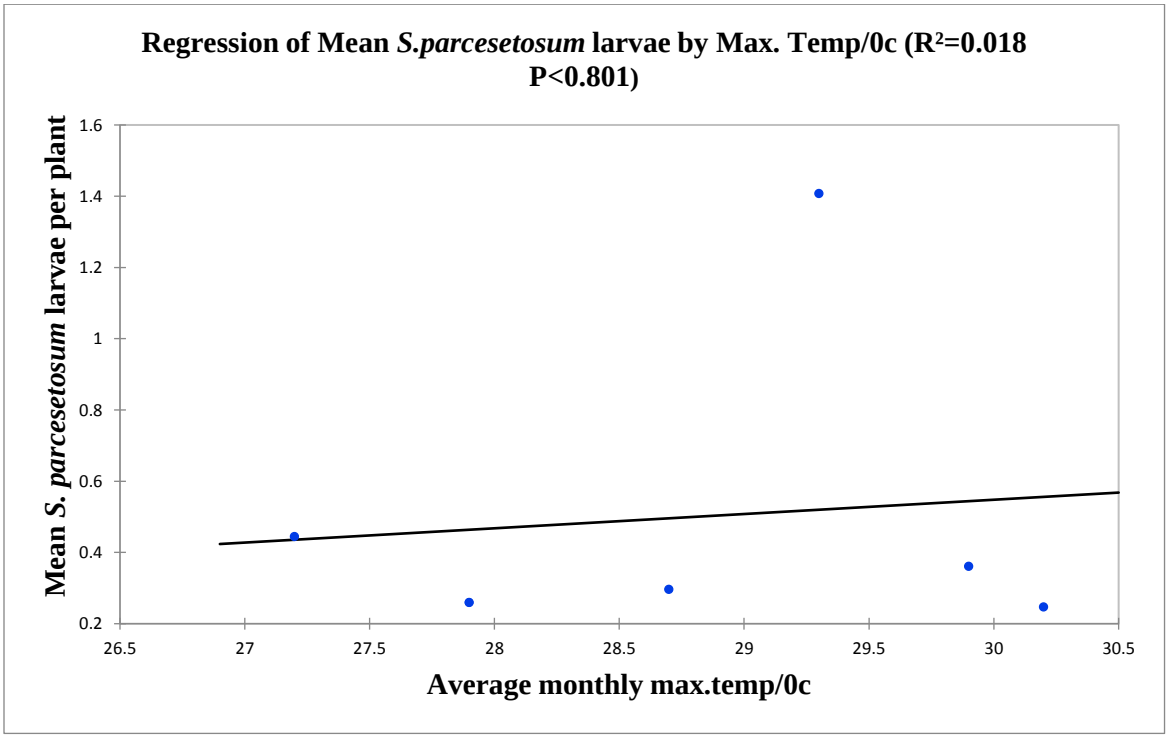
Regression of mean *Serangium parcesetosum* adults per plant by average monthly maximum temperature in Kamuli



Regression of mean *Serangium parcesetosum* larvae per plant by average monthly maximum temperature in Kamuli

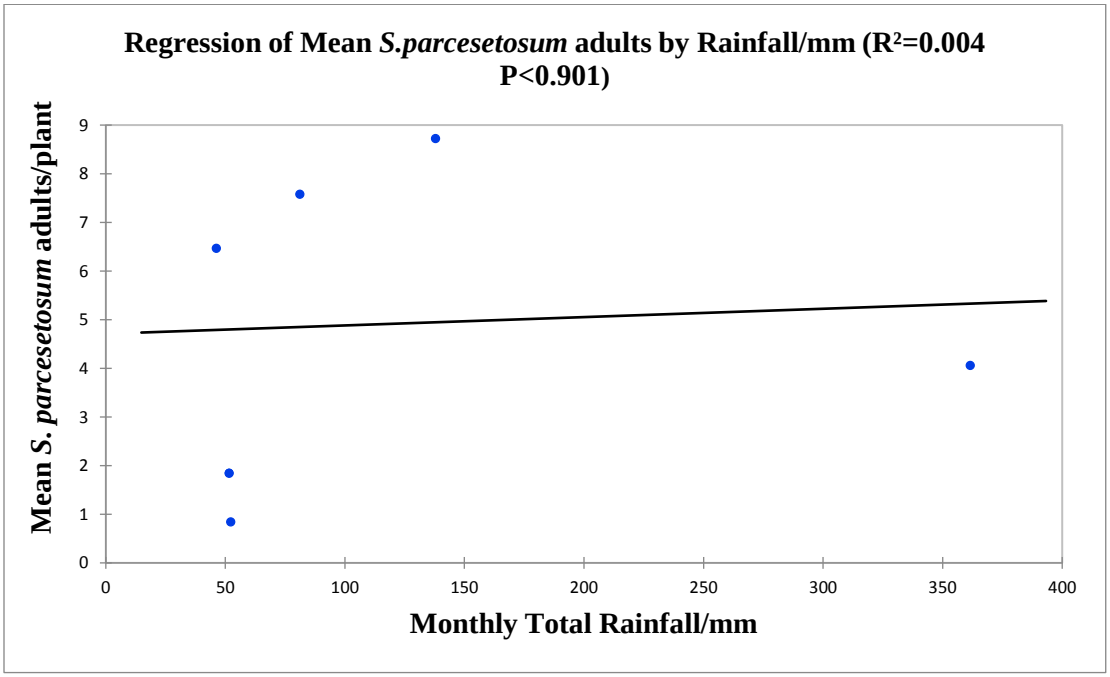


Regression of mean *Serangium parcesetosum* adults per plant by average monthly maximum temperature in Lira

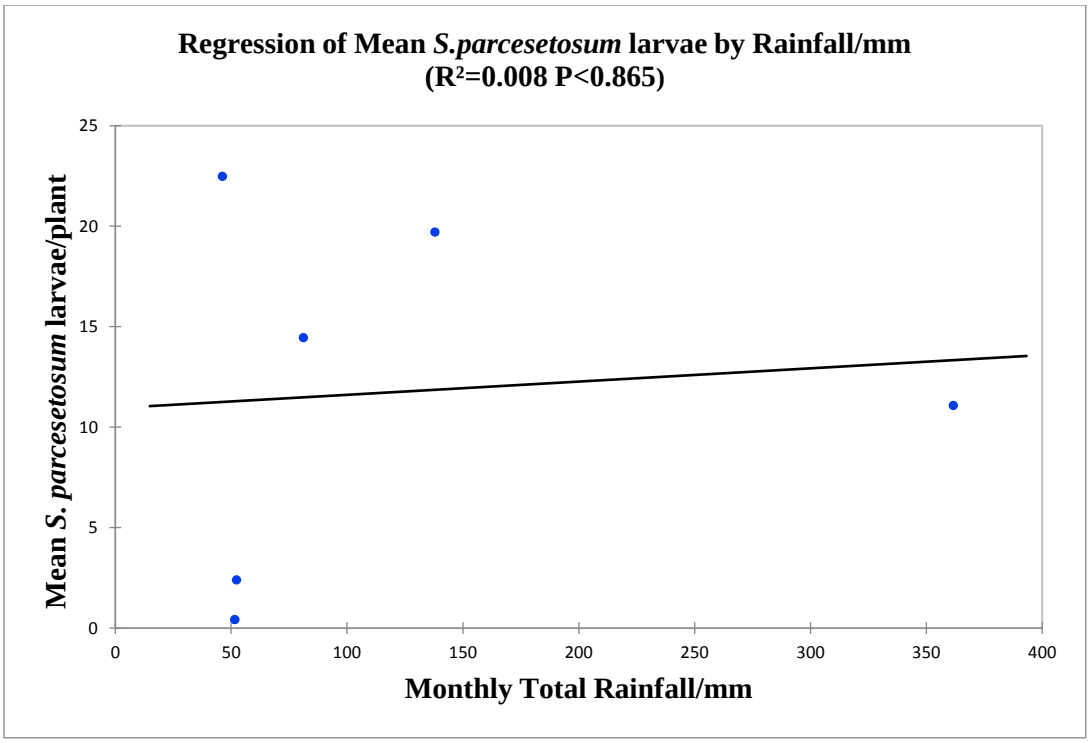


Regression of mean *Serangium parcesetosum* larvae per plant by average monthly maximum temperature in Lira

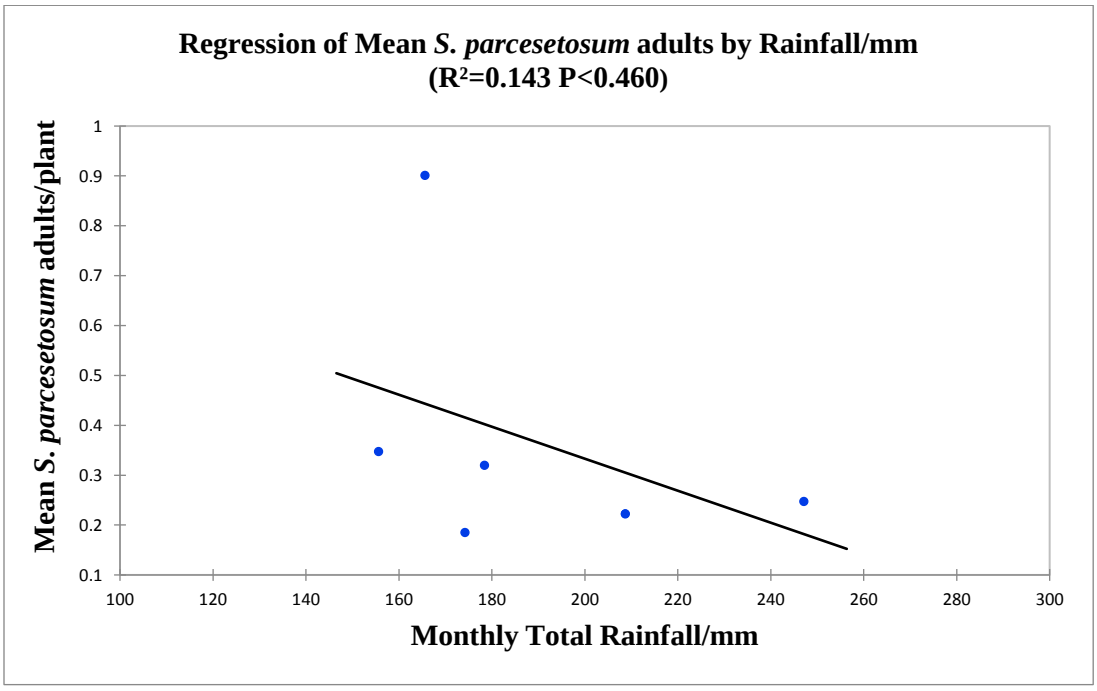
Appendix 5: Regression of *S. parcesetosum* population by rainfall



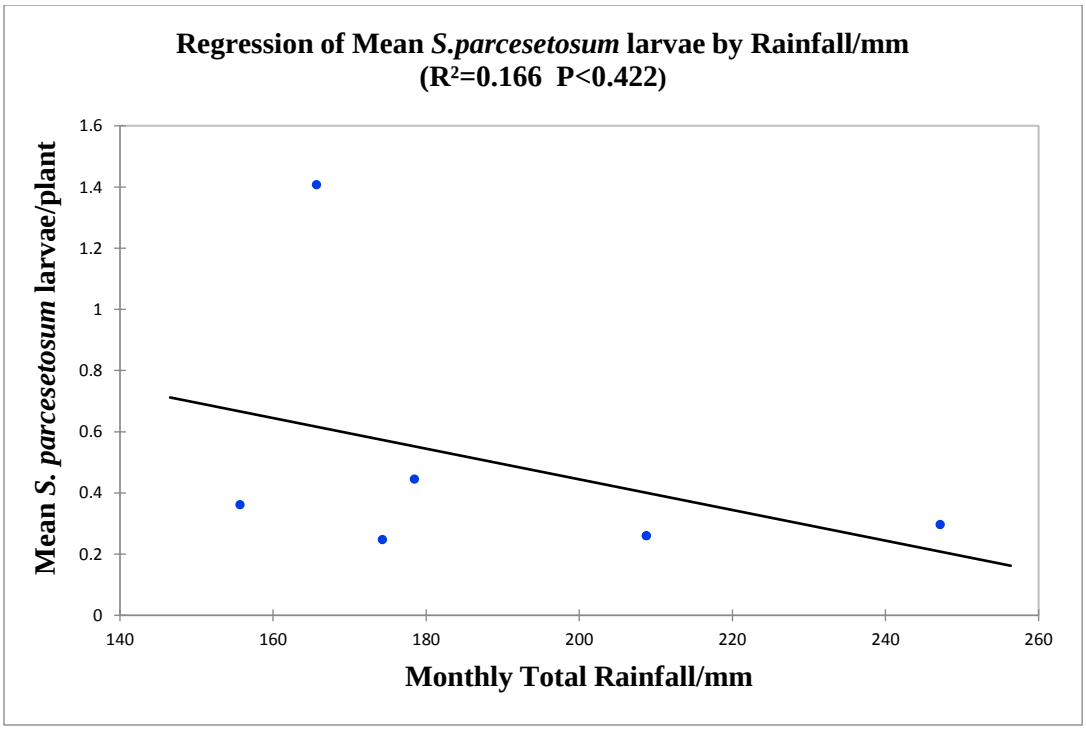
Regression of mean adult *Serangium parcesetosum* per plant by total monthly rainfall in Kamuli



Regression of mean *Serangium parcesetosum* larvae per plant by monthly total rainfall in Kamuli

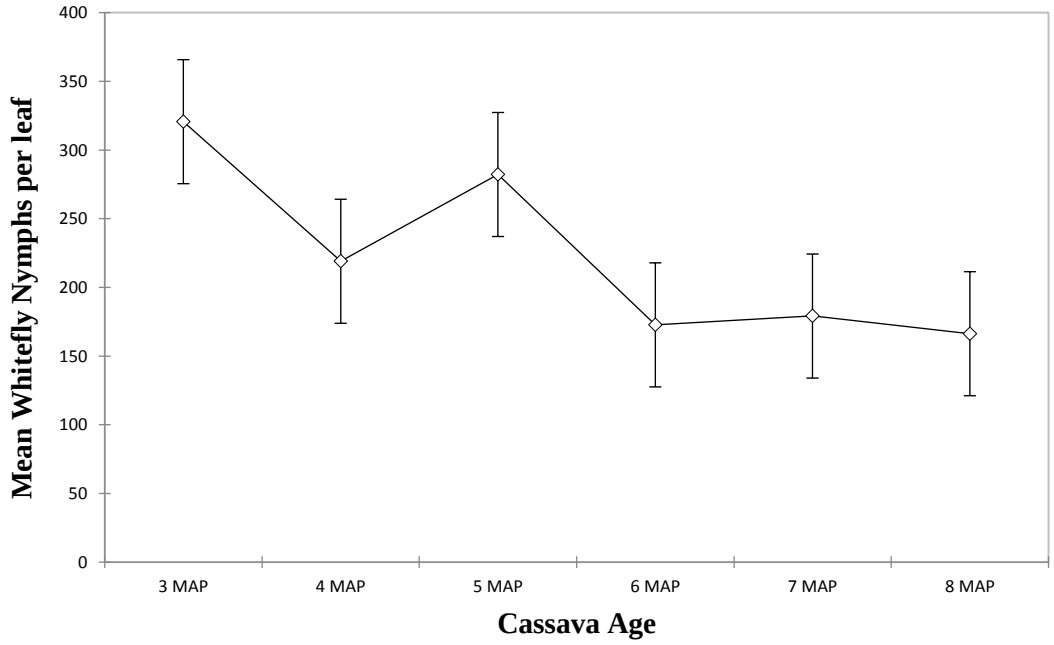


Regression of mean Serangium parcesetosum adults per plant by total monthly rainfall in Lira

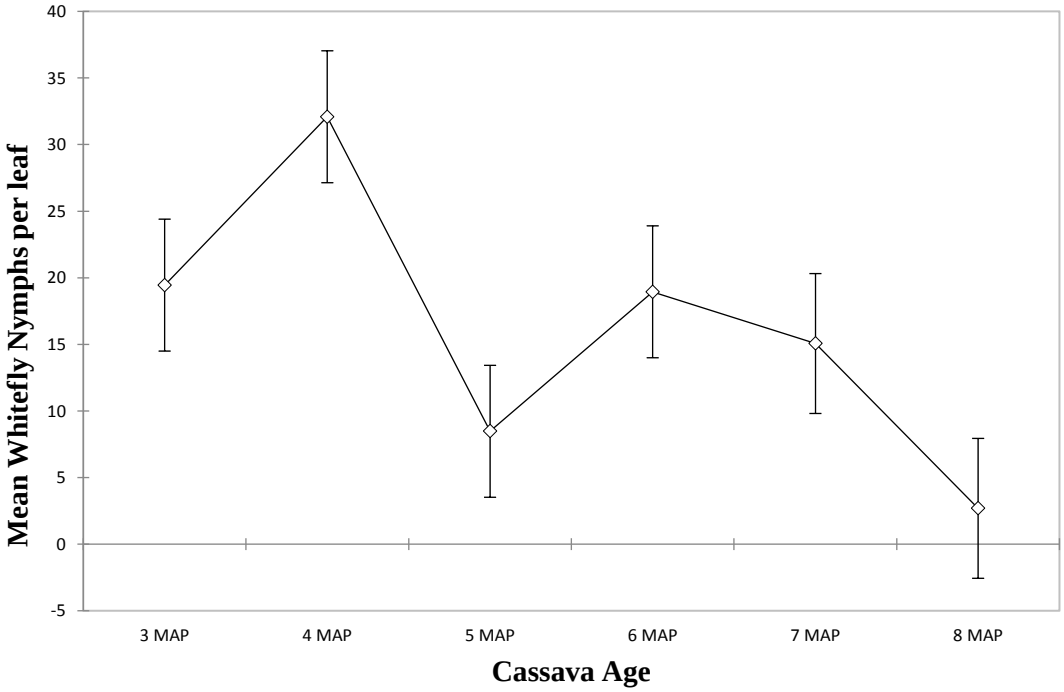


Regression of mean Serangium parcesetosum larvae per plant by total monthly rainfall in Lira

Appendix 6: Changes in the whitefly nymph population with cassava age



Changes in the mean whitefly nymph population per leaf with cassava age in Kamuli



Changes in the mean whitefly nymph population per leaf with cassava age in Lira

Appendix 7: Pictures of *S. parcesetosum* and whitefly nymphs in the field

Whitefly adult (R) and nymphs (L) feeding on the underside of cassava leaf in the Kamuli trial site

Source: Ocitti. P, Wamani.S, Opio.M.S, 2017 (Photo gallery)

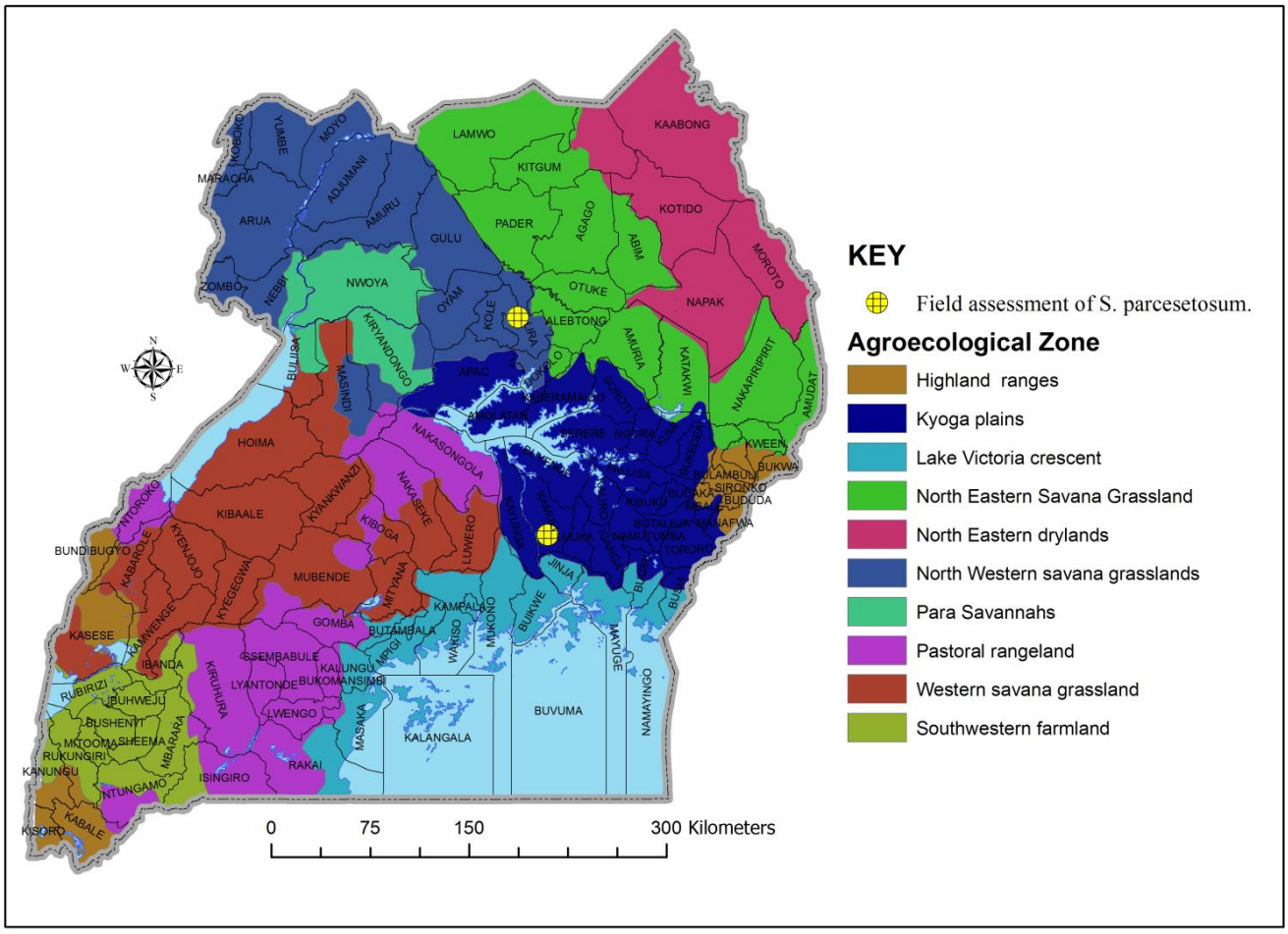
Serangium parcesetosum adult (R) and larva (L) feeding on the whitefly nymphs on the underside of cassava leaf in Kamuli trial site

Source: Ocitti. P, Wamani.S, Opio.M.S, 2017 (Photo gallery)

Appendix 8: Pictures of cassava varieties used in the experiment

Njule red (top left), Narocass1 (top right) and Nase 14 (bottom left). Cassava varieties used in the experiment

Appendix 9: A Map showing the different sites where the experiment was carried out



Appendix 10: Data collection on the Lira experimental site

Appendix 11: Field data sheet used for data collection of *S. parcesetosum* and whitefly nymph population

Field evaluation of S .parcesetosum - predator to cassava whitefly

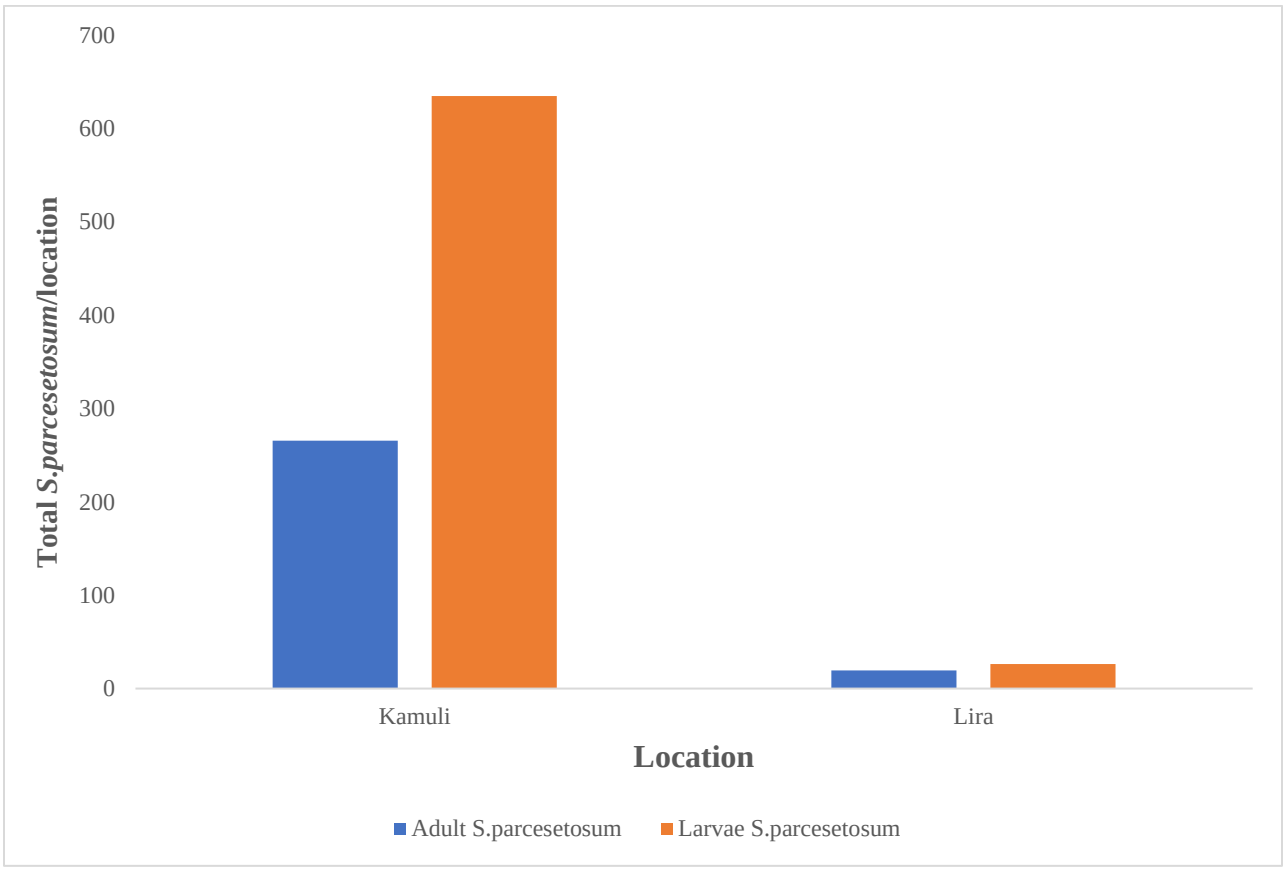
Location of experiment:…….. Rep No:……. Plot No:…….

Date of recording……..….Age:…... MAP) Cassava Variety:……

Recorded by:……

Plant No.	No. Adult Serangium.p.	No. serangium.p. larvae	No.whitefly nymphs	Remarks
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Average				

Appendix 12: Total *S. parcesetosum* population recorded in each location



Appendix 13: Agronomic and pedigree information on the varieties used in the study

Variety	Type	Year of Release	Disease reaction		Yield (t/ha)
			CMD	CBSD	
Nase 14	Improved	2011	Resistant	Tolerant	25 - 35
Narocass1	Improved	2015	Resistant	Tolerant	35 - 45
Njule Red	Landrace	N/A	Susceptible	Susceptible	Below 10

Source: Root crops program - National Crops Resources Research Institute and Kawuki et al., 2017