SUPRESSING POPULATIONS OF TOMATO LEAF MINER (*Tuta absoluta*) IN THE AGRO-ECOLOGICAL ZONES OF MOROGORO

PETER AMON MAERERE

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2018

EXTENDED ABSTRACT

Tomato leaf miner *Tuta absoluta* is a destructive and highly invasive insect pest of tomato and other solanaceous plants including plants in the family Fabaceae like beans. The range of host for the moth is extensive requiring in-depth surveys on both solanaceous and Fabaceae crops along with weeds to fully understand it. This study was aimed at understanding the spatiotemporal distribution of the moth along the Uluguru Mountains in Morogoro. The moth preference to alternative hosts and also efficacy of selected bio and synthetic insecticides in the management of the moth was also evaluated. From the results it was revealed that *T. absoluta* was present in all locations of the study in varying numbers. Weather factors such as rainfall and temperature had influence in the population of the moth. Population of the moth was determined by using delta traps loaded with para-pheromones on a sticky card that captured male moths. Trapping of the moth was conducted for 12 weeks for two growing seasons, 21 traps were used to trap the male moth for each season. Some weeks during trapping a high average population of 300 male moths were trapped while the lowest average population was 20 moths per week. Population fluctuation was observed to be influenced by the altitude of the location of trapping. Host preference was determined by sampling of plant leaves with visible damage of *Tuta absoluta* larva; The sampled leaves were placed in a plastic box with sand. Tomato (*Solanum lycopersicum L*), Eggplant (*Solanum melongena*), African eggplant (*Solanum aethiopicum*) and Amaranthus (*Amaranthus retroflexus*) were sampled in Morogoro Municipality and Mvomero district. Amaranthus was the least preferred of the host plants sampled compared to Tomato and Egg plant. Efficacy of synthetic and bio synthetic insecticides was determined in three locations using a synthetic insecticide Wiltigo and a combination of bio-insecticide Antario and recharge, Biotrine and recharge. The applied insecticides proved to be equally capable of controlling the moth in the field.

DECLARATION

I, Peter Amon Maerere, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

……………………………   …………………………

Peter Amon Maerere   **Date**

MSc. Crop Science Candidate

The above declaration is confirmed by

……………………………   …………………………

Prof. M. W. Mwatawala   **Date**

Supervisor

COPYRIGHT

ACKNOWLEDGEMENTS

I am grateful to the Lord for all the blessings and joy in my life. I would like to thank my family for provide me with unending inspiration and the support they have given me in the pursuit of this project. Especially my parents Prof. A. P. Maerere and Joyce Maerere, whose love and guidance are with me in whatever I pursue.

I am greatly indebted to my supervisor Prof. M. W. Mwatawala, who has been supportive and worked actively to provide me with guidance to achieve my academic goals. Thank you and may God bless you.

This work would not have been possible without the financial support of the East African Vegetable Crops Integrated Pest Management Innovations Lab (EAVCIPM – IL).

I would also like to thank all my classmates for their support, all the farmers in Dakawa, Mlali, Langali, Morogoro and Nyandira for their hard work and support. Not forgetting the Agricultural and village officers in Mvomero who worked tirelessly to facilitate this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Aw	-	Tropical wet and dry or Savanna climate; with the driest month having precipitation less than 60 mm (2.4 in) and less than 4% of the total annual precipitation.
Cwa	-	Monsoon-influenced humid subtropical climate; coldest month averaging above 0 °C (32 °F), at least one month's average temperature above 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (alternative definition is 70% or more of average annual precipitation is received in the warmest six months).
EPPO	-	European Plant Protection Organization
FAO	-	Food and Agriculture Organization
HSD	-	Highest significance difference
NEPPO	–	Near East Plant Protection Organization

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Biology and Pest Status of *Tuta absoluta*

Tomato leaf miner, *Tuta absoluta* (Meyrick) is a moth of the family Gelechiidae under the order Lepidoptera. The moth is a holometabolous insect with a high rate of reproduction, It is capable of producing 10-12 generations per year (Gebremariam, 2015), allowing the moth to be present throughout the tomato growing cycle. The female moths lay 73%, 21%, 5% and 1% of their eggs on the underside of the leaves, stems, sepals and fruits respectively. After 4 to 6 days the eggs hatches. The emerging larvae penetrate the leaves, stem or fruits, feeding on them and hence creating visible mines that reduce the photosynthetic ability of the crop. On the leaves the larvae feed between the epidermal layers, causing irregular mines that may later become necrotic. Tomato fruits are attacked during formation stage. The feeding sites of the larvae can later be infected by secondary pathogens causing fruit rot. The larvae undergo four instars before dropping to the ground in a silken thread and pupate in the soil for 10 days. The adult moths are small about 7 mm, they are brown or silver in colour with black spots on their wings (Pfeiffer *et al.*, 2013). The males are slightly darker and smaller than the females.

The presence of the tomato leaf miner in Tanzania was reported in August 2014 in Ngabobo, Ngarenanyuki and King'ori villages in the Arumeru district (Chidege *et al.*, 2016). Early warning of probable invasion of the pest was made in 2013 but no measures were taken. Major means by which the tomato leaf miner is spread is via trade routes by transporting tomato fruit or seedlings infested with the moth. Presence of the moth caused extensive damage of 80-100% of the crop in both greenhouses and open fields (Goftishu *et al.*, 2014). Tomato leaf miner feeds on the leaves, buds, stem and fruit reducing the yield and quality of the crop and hence the commercial value of the tomato fruit.

Benmessaoud (2011) reported that in Morocco the moth population in greenhouses was highest at periods of harvest when the temperature was at 30^0C unlike the larvae and egg population which was highly variable throughout the growing season.

Use of insecticides has drastically increased for the control of the tomato leaf miner. This has in turn led to increased cost of production to farmers as well as risk to human health and the environment. Increased use of insecticides has been reported by Gebremariam (2015) to cause development of insect resistance and resurgence by the moth and thus making it very challenging to control and limiting its spread. The increased use of insecticides also tends to negatively affect other beneficial insects like bees.

Tomato (*lycopersicum esculentum*) is one of the most important horticultural crops in the world. It is grown in both protected and open environments. China is the largest producer of tomato (34 million tons) in the world. The production of tomato is mainly faced by several constraints biotic and abiotic factors (Goftishu *et al.*, 2014). Among the abiotic factors are unfavourable climatic conditions and soil physico-chemical properties; and biotic factors limiting the yield of the crop are weeds, insect pests, and diseases (Mahmoud et al., 2015).

1.2 Problem Statement

Tomato leaf miner is a major cause of loss in tomato ever since its accidental introduction in Tanzania in the early 2010. The pest is known to affect all tomato varieties grown by farmers in the country. *Tuta absoluta is* a highly destructive and invasive pest capable of rapid adaptation to the new environment and it is known to resist some insecticides used to control it. Tomato production is highly affected by the moth’s presence from the nursery stage to harvesting, storage and marketing. Repeated use of insecticides is known to cause moth population resurgence. The moth is also known to complete its life cycle in other host plants creating a dilemma in the management of the moth. However resent developments and studies have shown promise in using bio-pesticides and natural enemies in controlling the moth.

1.3 Justification

Tomato is grown in many parts of Tanzania as a commercial and food crop. It is a major dietary source of vitamin C, potassium, folate, vitamin K, carbohydrates and fiber. The production of tomato represents 51% of the total vegetable production in Tanzania with an annual production of 129.578 tons (Minja *et al.*, 2011). In the country, tomato is produced in Iringa, Tanga, Dodoma, Mwanza, Shinyanga, Kilimanjaro, Mbeya, Dar es Salaam, Morogoro and Arusha regions. The presence of *T. absoluta* in areas growing tomato in Tanzania threatens the production and availability of quality tomato in the local markets. The moth is fast becoming a major constraint due to the damage it causes by reducing the photosynthetic capability of the crop and reducing commercial value of the tomato.

The presence of the moth in an exotic environment brings new challenges in its management. Because of the presence of different fauna and flora composition compared to its native habitat that has a different interaction on the moth population. In the exotic environment *T. absoluta* tends to flourish due to the absence of most of their common natural enemies and presence of abundant alternative hosts. The knowledge of the presence of the moth and the risk it poses is not enough information to develop and initiate appropriate strategies for control. Knowledge of the biology and life parameters of the moth is the most critical (Salama *et al.*, 2014) in knowing the influence of weather on abundance of the moth population and how its population dynamics responds (Cuthbertson *et al*., 2013). Pfeiffer (2013) presented laboratory findings on the effects of temperature on the life cycle of *T. absoluta*. At 14^0C, 20^0C and 27^0C, the moth survived for 76 days, 24 days and 24 days respectively. From these results, further studies on the influence of weather on the moth are thus required. Various researches have provided information on the moth's distribution in between plants and their abundance in greenhouses.

Common methods used by farmers to control *T. absoluta* include use of physical barrier (greenhouses), mass trapping using pheromones, use of chemicals, non-chemical means by using Neem oil (Azadirachtin), Good Agricultural Practices and Integrated Pest Management; like ploughing, adequate irrigation and fertilisation. Chemicals are the most widely used means of control of the moth. Effectiveness of the insecticide should be known and its effects on other insect either pests or beneficial, should also be considered so as to limit its impact on the environment (Santos *et al.,* 2011; Gacemi and Guenaou, 2012). Most recommended insecticides against the tomato leaf miner are those with either Imidacloprid, Indoxacarb, Spinosad or Deltamethrin as their active ingredients.

This research was undertaken in the agro-ecological zones of Morogoro to determine the abundance of the tomato leaf miner, establish the host range, infestation levels and compare the efficacy of selected insecticides under various environmental conditions. Results from this study will be useful in helping decision-makers in assessment of site-specific risks of invasion and spread of *T. absoluta* with a view to developing appropriate surveillance and management strategies. The study will also provide information to make farmers aware of the pest problem and to adopt appropriate control strategies.

1.4 Objectives

1.4.1 Overall objective

To assess the spatial and temporal distribution of *T. absoluta* and select moth population suppression techniques to reduce loss inflicted by *T. absoluta* on tomato grown in the agro-ecological zones of Morogoro.

1.4.2 Specific objectives

i) To determine the abundance of the *T. absoluta* across agro-ecologies.

ii) To establish host range and damage of *Tuta absoluta*.

iii) To compare effectiveness of selected control methods against *T. absoluta*.

REFERENCES

Benmessaoud-Boukhalfa, H. (2011). Spatiotemporal distribution of *Tuta absoluta* Mey. (Lepidoptera: Gelechiidae) in tomato greenhouses on the coast of Algiers. Cited [http://www.neppo.org/wpcontent/uploads/2014/05/anglais-oral-tuta-agadir1.pdf.] 16/10/2017

Chidege, M., Al-zaidi, S., Hassan, N., Julie, A., Kaaya, E., & Mrogoro, S. (2016). First record of tomato leaf miner *Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae) in Tanzania. *Agriculture & Food Security*, 5(1), 17- 32.

Cuthbertson, A. G., Mathers, J. J., Blackburn, L. F., Korycinska, A., Luo, W., Jacobson, R. J., and Northing, P. (2013). Population development of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) under simulated UK glasshouse conditions. Insects, 4(2); 185-197.

Gacemi, A., & Guenaoui, Y. (2012). Efficacy of emamectin benzoate on *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) infesting a protected tomato crop in Algeria. *Academic Journal of Entomology*, 5(1); 37-40.

Gebremariam, G. (2015). *Tuta Absoluta*: A Global Looming Challenge in Tomato Production, Review Paper. Journal of Biology, Agriculture and Healthcare. 5(14); 26 – 35.

Goftishu, M., Seid, A., & Dechassa, N. (2014). Occurrence and Population Dynamics of Tomato Leaf Miner [*Tuta absoluta* (Meyrick), Lepidoptera: Gelechiidae] in Eastern Ethiopia. *East African Journal of Science*, 8(1), 59-64.

Mahmoud, Y. A., Ebadah, I. M. A., Abd-Elrazek, A. S., Abd-Elwahab, T. E., & Masry, S. H. D. (2015). Population fluctuation of tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) during winter and summer plantations in Egypt. RESEARCH JOURNAL OF PHARMACEUTICAL BIOLOGICAL AND CHEMICAL SCIENCES, 6(4), 647-652.

Minja, R. R., Ndee, A., Swai, I. S., & Ojiewo, C. O. (2011). Promising improved tomato varieties for eastern Tanzania. *African Journal of Horticultural Science*, 4(1); 17- 21.

Mwatawala M. W. (2017, October 10). *Tuta absoluta yet another invader at the Tanzanian doorstep*. Reading presented at *Tuta absoluta*: Meeting the challenge of the tomato leafminer. Intercontinetal Hotel, Addis Ababa, Ethiopia, November 26-28th, 2013 in Ethiopia, Addis Ababa.

Pfeiffer, D. G., Muniappan, R., Sall, D., Diatta, P., Diongue, A., & Dieng, E. O. (2013). First record of *Tuta absoluta* (Lepidoptera: Gelechiidae) in Senegal. *Florida Entomologist*, 96(2), 661-662.

Salama, H., Fouda, M., Ismail, I. A., Ebada, I., & Shehata, I. (2014). Life table parameters and fluctuations in the population density of the moth *Tuta absoluta* (Meyrick)-(Lepidoptera: Gelechiidae). Current Science International, 3(3), 252-259.

Santos, A. D., Bueno, R. D. F., Vieira, S. S., & Bueno, A. D. F. (2011). Efficacy of insecticides on *Tuta absoluta* (Meyrick) and other pests in pole tomato. Bioassay, 6(4), 1-5.

CHAPTER TWO

2.0 SPATIAL AND TEMPORAL ABUNDANCE OF TOMATO LEAF MINER

2.1 Abstract

Tomato leaf miner is a destructive pest of tomato and other Solanaceae crops. The pest invaded Tanzania in 2013 and caused serious losses to tomato producers. The spatial and temporal abundance of the moth was determined by setting up Delta traps (Russell IPM) loaded with Tuta lure. The surveys were conducted from December 2016 to August 2017. Nine plots were established in three locations Mlali (572 m asl), Langali (1131 m asl) and Nyandira (1678 m asl). The established plots along the slope of the Uluguru Mountains were to provide periodic data on the moth population per location over the two-growing season. Trapping was conducted for two tomato growing seasons. The number of moth trapped was collected weekly. Results showed that population of the trapped moth was highly significant between the locations and the moth was present throughout the survey period, with the highest population recorded in Nyandira. Trap catches observed varied significantly between the locations and overtime for both growing season independently.

Keywords: *Tuta absoluta***,** Spatial, temporal, abundance, Morogoro and tomato.

2.2 Introduction

Tomato leaf miner *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is a serious invasive and polyphagous pest that invaded Eastern and Southern Africa recently. The pest is of South American origin, recorded in Chile in 1964 (Bayindir *et al.,* 2016). The moth has spread rapidly from its origin in South America to Europe and Africa causing extensive damage along its path. Factors that determine abundance and distribution of *T. absoluta* include air and soil temperature, availability and age of the host. *Tuta absoluta* attacks various crops that include eggplant (*Solanum melogena*), potato (*Solanum tuberosum* L.), pepper (*Capsicum spp*.), tobacco (*Nicotiana tabacum* L.), common bean (*Phaseolus vulgaris* L.) and Solanaceous weeds (Korycinska and Moran, 2009; EPPO, 2009). The moth has been regarded as a major pest of tomato in a short period of time because its presence in the field or greenhouse could cause 80 – 100% damage to the crop (Goftishu *et al.*, 2014). Losses due to *T. absoluta* range from foliage mining to leaves drying.

Tomato leaf miner spread from its native region to Europe where it was detected in Spain and across the Mediterranean coast (EPPO, 2008). Later it spread to northern African countries Morocco, Algeria, Tunisia, Libya and Egypt. From Egypt, the moth spread south into Sudan (Temerak, 2011), Ethiopia and Kenya (Goftishu *et al.*, 2014). *Tuta absoluta* was first detected in Tanzania in Arumeru district in Arusha (Chidege *et al.,* 2016). The pest spread throughout Tanzania along the major tomato distribution channels by transportation of infested seedlings, fruits and containers.

Tomato is an important vegetable crop grown in many parts of Tanzania as a commercial and food crop. Its overall production represents 51% of the total vegetable production in Tanzania with an annual production of 129,578 tons (Minja *et al*., 2011). The main production regions in Tanzania are Iringa, Tanga, Kilimanjaro, Mbeya, Dar es salaam, Morogoro and Arusha (Maerere *et al.,* 2006).

Spatial and temporal distribution of *T. absoluta* is highly dependent on the availability of the host species, absence of natural enemies and presence of favourable climatic conditions (Mohammed *et al.,* 2015). Presence and number of tomato plants greatly influences the distribution of the moth in an area over time. Management of *T. absoluta* is mainly done by chemical means using various chemical insecticides with varying effectiveness. Insecticides with Imidacloprid, Indoxacarb, Spinosad, Chlorantraniliprole or Deltamethrin as their active ingredients are mainly recommended for the control of the moth (Sridhar, 2016). Most recently the use of bio-insecticides, para-pheromone traps and natural enemies like *Pseudapantees dignus* and *Dineulophus phthorimaeae* have been reported by Coviella (2015) to have potential as suitable control measures for the moth.

2.3 Materials and Methods

2.3.1 Study locations

The study was conducted in three agro-ecological zones along the slopes of the Uluguru Mountains in Morogoro Tanzania. Three villages were surveyed, Mlali in the river valley, Langali in the intermediate zone and Nyandira in the mountain zones. The coordinates and altitudes of the location surveyed are shown in Table 1 below.

Table 1: Altitude and geographical positions (Coordinates) of the survey sites

LOCATION	ALTITUDE (m)	LATITUDE	LONGITUDE
Mlali	572	S06^0 57’ 38.4”	E037^0 32’ 01.1”
	578	S06^0 58’ 03.4”	E037^0 30’ 41.5”
	585	S06^0 58’ 45.5”	E037^0 31’ 30.2”
Langali	1143	S07^0 03’ 18.6”	E037^0 34’ 42.9”
	1131	S07^0 03’ 31.9”	E037^0 34’ 42.9”
	1126	S07^0 03’ 41.8”	E037^0 34’ 38.6”
Nyandira	1540	S07^0 04’ 43.1”	E037^0 34’ 51.5”
	1678	S07^0 05’ 07.62”	E037^0 34’ 49.07”
	1680	S07^0 05’ 13.97”	E037^0 34’ 51.78”

2.3.2 Determination of the spatial and temporal abundance of *Tuta absoluta*

Three plots were established in each location. Each plot measured 5 m by 10 m. Plots were established 500 m or more apart. A nursery to raise tomato seedlings was established in Mlali using the variety Asila. The seedlings were transplanted on 30th December 2016 and 5th May 2017 for the first and second season respectively. Recommended agricultural practices were performed. The plots were not sprayed with insecticides during the entire period of the study. A delta trap (Russell IPM, UK) baited with a commercial para-pheromone lure (Optima PH-937-OPTI, Russell IPM, UK) was set in each plot. Trapping duration was 3 months replicated for two tomato growing seasons; December 2016 to March 2017 and from June 2017 to August 2017.

Data collection started a week after transplanting. The delta traps loaded with the pheromone lure that is used to capture the adult male moth only (Witzgall *et al.,* 2010) was used. The numbers of adult male moths were recorded weekly and the sticky cards were then replaced. The para-pheromone was changed every four weeks. At each location as shown in Table 1, the numbers of male moths trapped per trap were recorded.

2.3.3 Data analysis

Repeated measures ANOVA was run for the two seasons separately, to determine significance between the three locations. Then simple one-way ANOVA was run for each individual location per season. Tukey test was used for means separation of the location, season and weeks after transplanting. Data were analysed using the Minitab software 18. All statistical tests for significance were performed at $P \leq 0.05$.

2.4 Results

2.4.1 Spatiotemporal distribution of *Tuta absoluta*

Population of *T. absoluta* moths was abundant throughout the two growing seasons in all three locations. The population of the moth was higher at the beginning of the first season with a mean of 190.5$\pm$ per week but later declined from the 7th week. For the second growing season, the number of trapped moths was low throughout the season averaging 62.5$\pm$ per week.

2.4.2 Abundance of *Tuta absoluta* in the 1st growing season

Results of the first season trapping showed that, the population of moths varied significantly among altitudes ($F_{(2)}$= 29.63, P = 0.000326). There was no significant difference in population recorded for the first growing season in Mlali. Highest population of the moths was recorded in Nyandira (1632 m asl). The abundance of moths also varied significantly over time ($F_{(11)}$ = 5.87, P = 0.000127). Significant effects of altitude x time were also recorded ($F_{(24)}$= 3.74, P= 0.00013). One way ANOVA results for each altitude showed that populations of the moths significantly varied over time in Nyandira

($F_{(11)}$=5.747, P= 0.000173) and Langali ($F_{(11)}$ = 4.668, P = 0.000784). Post Hoc Tukeys' HSD test revealed significant pairwise differences of moth populations in Langali between week 11 and the weeks 3,5 and 6 at P 0.01, 0.0402 and 0.0112 respectfully (Fig. 1). A similar pattern can be observed between week 12 and weeks 3, 5 6 where week 12 had the lowest population of the moths. A siginificant drop in population of Tuta in Nyandira in the first season was observed in the 9th week. Population was highest in week 2 after trapping. Tukeys' HSD places the significance of the drop from week 2 to week 9 and 10 at P< 0.01 (Fig. 2).

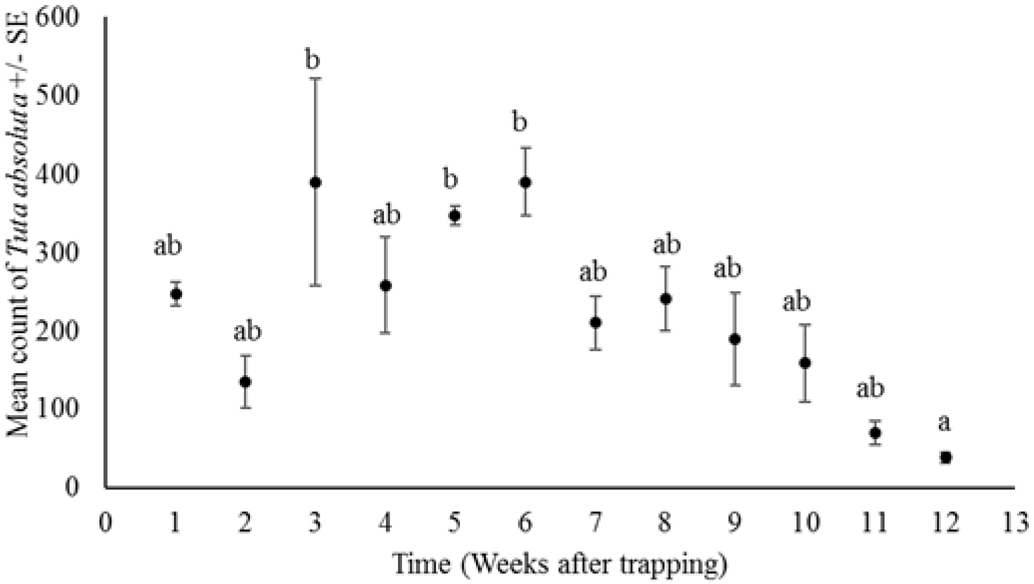

Figure 1: Mean (+SE) population of trapped moth for the first growing season at Langali (1126 – 1143 m asl). (Bars that do not share a letter represent significantly different means by Tukeys HSD)

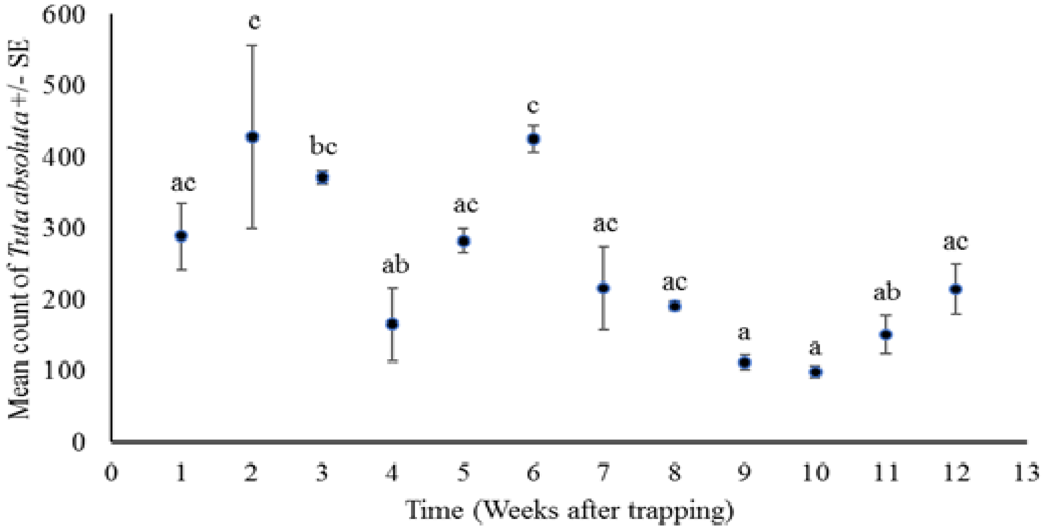

Figure 2: Mean (+SE) population of trapped moth for the first growing season at Nyandira (1540 – 1680 m asl). (Bars that do not share a letter represent significantly different means by Tukeys HSD)

2.4.3 Abundance of *Tuta absoluta* in the 2nd growing season

During the second season, the population of adult *T. absoluta* changed significantly with altitude ($F_{(2)}$ = 6.88, P =0.002). Peak population was recorded in Mlali (578 m asl). The population of moths also differed significantly with time ($F_{(11)}$ =, P= 0.0002).

Significant effects of altitude x time were also observed ($F_{(24)}$ =3.74, P= 0.012). The variation of populations of moth's overtime within each altitude was also significant. As the population dropped in the second season, trappings in Mlali (580 m asl) significantly varied between the weeks as opposed to the 1st growing season ($F_{(11)}$ =3.1, P = 0.01). Post hoc test Tukey's revealed that populations in Mlali (580 m asl) during 2nd growing season were lowest in week 8 and highest in week 12 where there was an increase in 148 moths' in traps (Fig. 3). This increase was significant at P< 0.01. Mean populations of adult *T. absoluta* over time in the second season in Langali (1130 m asl) was significantly different ($F_{(11)}$ = 7.032, P = 0.0000351). Tukeys HSD test demonstrated that the population remained below 60 till the sixth week where a significant rise is observed in comparison to the first week (*P*=0.0177). The highest significant difference in population was between the first and 9th week (106 moths) (Fig. 4). Populations remained relatively the same in Nyandira (1580 m asl) in most weeks and significantly rose in the last three weeks of season 2 (Fig. 5)

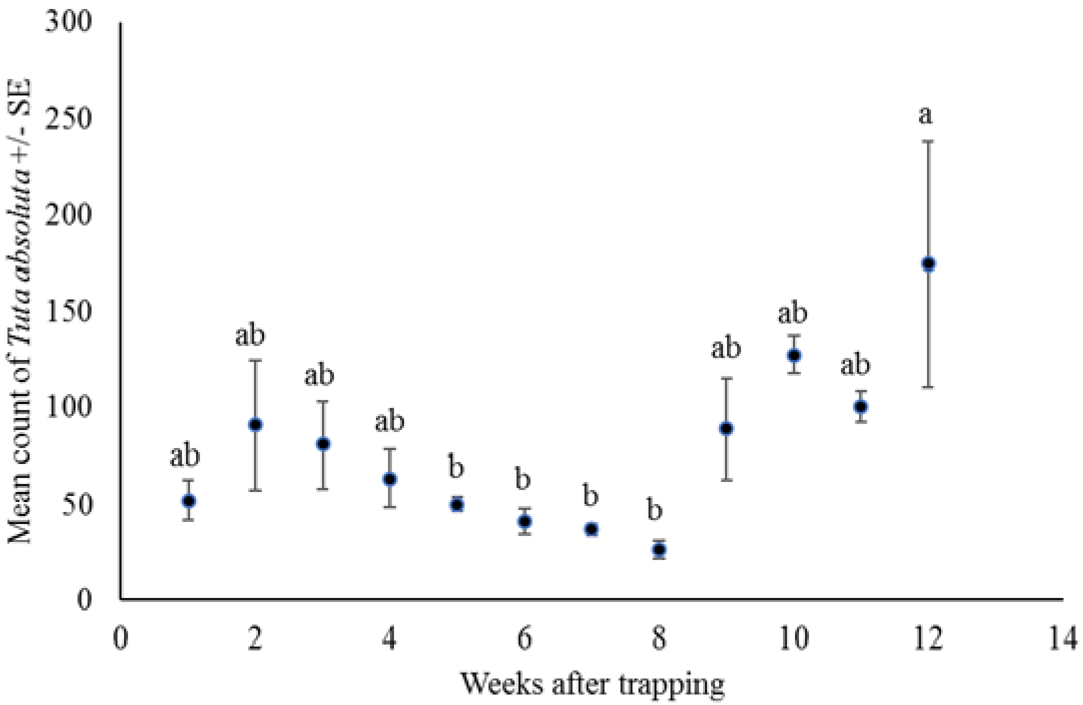

Figure 3: Mean (±SE) population of trapped moth for the 2nd growing season at Mlali (572 – 585 m asl). (Bars that do not share a letter represent significantly different means by Tukeys HSD)

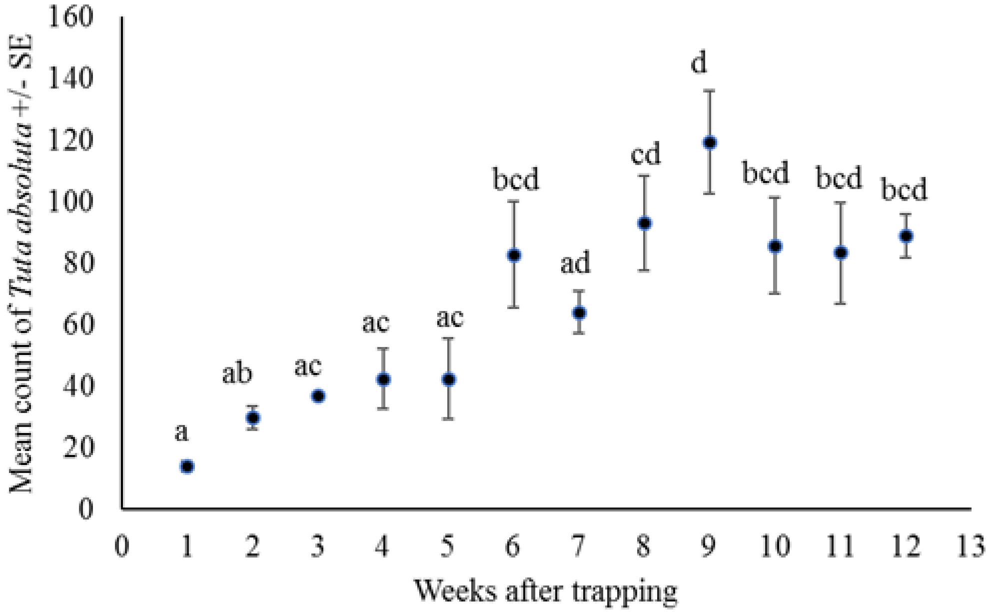

Figure 4: Mean (+SE) population of trapped moth for the 2nd growing season at Langali (1126 - 1143 m asl). (Bars that do not share a letter represent significantly different means by Tukeys HSD)

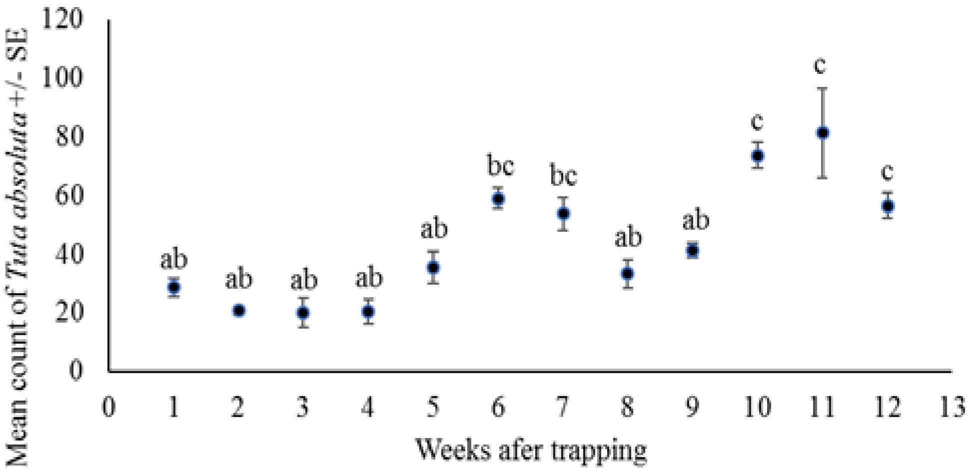

Figure 5: Mean (+SE) population of trapped moth for the 2nd growing season at Nyandira (1540 -1680 m asl). (Bars that do not share a letter represent significantly different means by Tukeys HSD)

2.5 Discussion

The result showed that the moth was present in large numbers in Langali and Nyandira compared to Mlali. This is due to the climatic condition of the two locations being more favourable to the moth development. The low moth count in Mlali was attributed to the high temperature recorded in the 1st growing season averaging 27^{0}C. High temperature of the location as the capability to decrease the development time of the moth between the range of 15 – 29^{0}C reported by Özgökçe (2016). The presence of viable host plants surrounding areas cultivating tomato provided the moth with suitable environment to complete their life cycle and allows the moth to be present throughout the year in all three locations.

Mlali is classified as *Aw* by Köppen and Geiger, the average annual temperature is 25.8^{0}C and about 1047 mm of precipitation falls annually (Beck., *et al*., 2006). With most of the precipitation falling in March averaging 468 mm, July being the coldest month with temperatures averaging 23.6^{0}C. The climate in Langali and Nyandira is classified as *Cwa* by Köppen and Geiger, with an average temperature of 20.7^{0}C and 1473 mm of precipitation falling annually. The driest month is August, with 18 mm of rainfall while most of the precipitation falls in April at an average of 528 mm. December is the warmest and July is the coolest month with an average temperature of 22.8^{0}C and 17.6^{0}C respectively. Hence Langali and Nyandira are the most favourable breeding sites for the moth.

Tomato leaf miner population in the first growing season which started in December 2016 to March 2017 was initially high for the first six weeks with 200 moths trapped per week and later dropped significantly below 150 trapped moths per week. In the 2nd growing season (May 2017 to August 2017) had the lowest moth population, with the initial eight weeks having a mean population below 60 moths per week. The highest mean population reaching 110 moths per week. The fluctuations in the populations of *T. absoluta* can be attributed to the changes in temperature and the heavy rains the locations received from March to May 2017.

With the long period of heavy rains, the number of moths trapped drastically declined. Due to the soil being extremely wet creating unfavourable conditions for the moth larvae to pupate in the soil. The drastic rise in the number of moth trapped is suggested to occur during periods of moderate temperature, while the minimum populations are observed in the lower or higher temperature periods (Mahmoud *et al*., 2015 & Ozgokce, 2016). Plant variability's like physiological state of the plant, climatic conditions in plant resource may have a significant impact on the spatiotemporal distribution of the moth (Goftishu *et al*., 2014).

2.6 CONCLUSION

The study has confirmed the continuous presence of the moth throughout the two major Tomato cultivation seasons along the Uluguru Mountain slope. Use of pheromone traps was observed to be a reliable means for monitoring the *Tuta absoluta* occurrence and population. With the highest *Tuta absoluta* population recorded in Nyandira (1540 m asl) and the lowest in Mlali (540 m asl). The results show that locational attributes like altitude and atmospheric differences between locations have significant influence on the moth population.

REFERENCES

APHIS-USDA. (2011). New pest response guidelines, Tomato leafminer (*Tuta absoluta*) [http://www.aphis.usda.gov/import_export/plants/manuals/emergency/downloads/*Tuta-absoluta*.pdf]. 25/10/2017

Bayindir, A., Karaca, I., and Salih Özgökçe, M. (2016). Temperature-dependent development of the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) on tomato. *Turkish Journal of Entomology*. 40 (1): 51-59

Beck, C., Rudolf, B., Rubel, F., Grieser, J., and Kottek, M. (2006). World Map of the Koppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15(3): 259-263.

Chidege, M., Al-zaidi, S., Hassan, N., Julie, A., Kaaya, E., & Mrogoro, S. (2016). First record of tomato leaf miner *Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae) in Tanzania. Agriculture & Food Security, 5(1); 17.

Coviella, C. E., Luna, M., Pereyra, C. P., Nieves, E., Savino, V., Salas-Gervassio, N. G., Luft, E. , Virle, E. and Sanchez, N. E. (2015). Potential of biological control agents against *Tuta absoluta* (Lepidoptera: Gelechiidae). *Florida Entomology Society*. 98(2):489-494.

EPPO (European and Mediterranean Plant Protection Organization). (2009). *Tuta absoluta* found on Phaseolus vulgaris in Sicilia (IT). EPPO Reporting Service 8, (3).

Gebremariamd, G. (2015). *Tuta absoluta*: a global looming challenge in tomato production, review paper. *J Biol Agric Health*, 5(14), 57-62.

Goftishu, M., Seid, A., and Dechassa, N. (2014). Occurrence and Population Dynamics of Tomato Leaf Miner (*Tuta absoluta* (Meyrick), Lepidoptera: Gelechiidae) in Eastern Ethiopia. *East African Journal of Science*, 8(1), 59-64

Korycinska, A., & Moran, H. (2009). South American tomato moth *Tuta absoluta*. South American tomato moth *Tuta absoluta*. Plant Pest Notice, No. 56.

Maerere, A. P., Sibuga, K. P., Mwajombe, K. K., Kovach, J. and Erbaugh, M. (2006). Baseline survey report of tomato production in Mvomero district-Morogoro region, Tanzania. Sokoine University of Agriculture Faculty of Agriculture, Morogoro. 31pp.

Mahamoud, Y. A., Ebadah, M.A., Abd-Elrazek, A. S., Abd-Elwahab, T. E., and Masry S H. (2015). Population Fluctuation of Tomato Leaf Miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) During Winter and Summer Plantations in Egypt. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*. ISSN: 0975-8585

Minja, R. R., Ndee, A., Swai, I. S., & Ojiewo, C. O. (2011). Promising improved tomato varieties for eastern Tanzania. *African Journal of Horticultural Science*, 4(1).

Mohammed A.M. Elhaj, Azhari O. Abdelbagi, Mahdi A. Ahmed, Mohammed E.E. Mahmoud. (2015). Seasonal abundance and host preference of Tomato leaf miner *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) in Khartoum, Gezira and Kassala States of the Sudan. *Journal of Agriculture and Natural Resource Sciences*. 2(3).

Özgökçe, M. S., Bayındır, A., & Karaca, İ. (2016). Temperature-dependent development of the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) on tomato plant *Lycopersicon esculentum* Mill.(Solanaceae). *Turkish Journal of Entomology*, 40(1).

Russell IPM. (2012). *Tuta absoluta* products. [http://russellipmagriculture.com/solutions.php?id_ctg=1&lang=en]. (Accessed, 18th July 2017)

Saini R. K, Yadav G. S, Kumari B. (2014). Compendium of lectures delivered during the Advanced Training Course on "Novel Approaches in Pest and Pesticide Management in Agro-Ecosystem". 19th August to 8th September, 2014. In: Centre of Advanced Faculty Training (CAFT). CCS Haryana Agricultural University, Hisar, Department of Entomology, 338 pp

Sridhar, V. and Nitin, K. S. (2016). Efficacy of new molecules of insecticides against South American tomato moth, Tuta absoluta (Meyrick)(Lepidoptera: Gelechiidae). Pest Management in Horticultural Ecosystems, 22(2).

Temerak S. A. (2011). The status of *Tuta absoluta* in Egypt. EPPO/IOBC/FAO/ NEPPO Joint International Symposium on management of *Tuta absoluta* (tomato borer, Lepidoptera: Gelechiidae) in collaboration with the IRAC and IBMA, Agadir, Morocco, November 16-18, 2011.

Witzgall, P. Kirsch, P. and Cork, A. (2010). Sex pheromones and their impacts on pest management. *Journal of Chemical Ecology* 36: 80– 100.

CHAPTER THREE

3.0 Management options for tomato leaf miner (*Tuta absoluta)* (Meyrick) (Lepidoptera: Gelechiidae) in Morogoro, Eastern Central Tanzania.

3.1 Abstract

The tomato leaf miner *Tuta absoluta* is an invasive pest recorded in Tanzania in 2013. The polyphagous pest tends to severely damage tomato at various growth stages and cause heavy losses to producers. Management techniques against tomato leaf miner were evaluated in Morogoro for two growing seasons from December 2016 to March 2017 and from June 2017 to August 2017. The evaluated treatments were a combination of bio-insecticide Antario (Bacillus thuringiensis var kurstaki 1.4% and Abamectin 0.1%) and recharge, Biotrine (Abamectin 5%) and Recharge (Metarhizium anisopliae 2%); and Wiltigo (Emamectin Benzoate) a synthetic insecticide. Another aspect of the management of the investigated moth was the host preference of tomato leaf miner in three locations. In order to identify the immediate host range so as to help farmers in tomato cultivation to understand and prevent the invasion and colonization by the moth. Generally, from the results it was observed that synthetic and bio insecticide had an equal ability to control the moth in all growing seasons, with a highly notable difference in a plot applied with a combination of Antario and recharge in Mlali on the second season having the lowest moth population. While for the host preference Tomato was the most preferred and Amaranthus was the least preferred of the four host plants surveyed.

Keywords: Tomato leaf miner, *Tuta absoluta*, host preference, management, biopesticide,

3.2 Introduction

Tomato (*Solanum lycopersicum*) is an important edible and nutritious vegetable, it belongs to the solanaceae family grown in rain fed and irrigated fields. Tomato production is faced by biotic and abiotic constraints (Goftishu *et al.,* 2014). Abiotic factors being unfavourable weather conditions and soil characteristics while, the biotic constraints being diseases like root rot, stem cut and late blight (Sanga *et al.,* 2016). Moreover, other insect pest like Whiteflies, Aphids and mites such as Red spider mites are common pests of tomato in many tomato growing regions of Tanzania.

The Tomato leaf miner *Tuta absoluta* (Meyrick) (Lepidoptera, Gelechiidae) is an invasive pest of tomato originally from South America (EPPO, 2009). *Tuta absoluta* was first detected in Tanzania in Arumeru district in Arusha region in 2013 (Chidege *et al.,* 2016). The pest has so far spread throughout Tanzania along all the major tomato distribution channels by transportation of infested seedlings, fruits and used containers. It has become a major pest in tomato production because it tends to affect the tomato plant in all stages of production from seedling to fruiting (Shehata, 2016).

Presence of the moth in a susceptible host crop fields increases cost of production of tomato and other solanaceous crops. Control of the moth is excessively hard for many reasons. The moth is able to resist insecticide (Siqueira *et al.,* 2000 and Siqueira *et al.,* 2001) and reproduces rapidly on a wide range of hosts (Desneux *et al.,* 2010). The larvae are the most destructive stage of the moth's life cycle, feeding vigorously producing large galleries in leaves. The larvae of *Tuta absoluta* tend to feed on the mesophyll cells of all aerial parts of the plants, as well as on the fruits which in turn protect the larvae from insecticides (Bawin *et al.,* 2015).

Tuta absoluta attacks the above ground plant parts; the leaves, buds, stem and fruits. The pest can cause up to 100% yield losses (Mahmoud *et al*., 2015). Plant parts attacked by the moth are sometimes points of entry for infection from fungal and bacterial diseases (Pfeiffer *et al.,* 2013).

The larva cause damage to the leaf, stem and tomato fruit attacking the tomato plant at any crop stage (Pfeiffer *et al.,* 2013). *Tuta absoluta* also attacks other crops of the solanaceae family like eggplant, bell pepper, sweet pepper and potato. Weeds like black nightshade (*Solanum nigrum*) and tree tobacco (*Nicotiana glauca*), and other plants like Slender amaranth (*Amaranthus viridis*), Johnson grass (*Sorghum halepense*) and Cutleaf groundcherry (*Physalis angulate*).

Common strategy used to control *Tuta absoluta* is by chemical means, using insecticides with diverse active ingredients. Use of insecticides can lead to resurgence of the moth population. Various environmental friendly methods have been suggested to better control the moth like cultural method by removing and destruction of infested plants, use of natural enemies and use of sex pheromone for mating disruptions of the moth (Megido *et al.,* 2013). These strategies are suggested so as to reduce the use of chemical means for the control of tomato leaf miner.

Controlling the moth by chemical means tends to be ineffective against the most destructive stage of the moth which is the larvae. The larva mines into the tomato fruits and leaves therefore becoming inaccessible to contact insecticides. Alternative control strategies include mass trapping by placing large numbers of traps in strategic position to trap males. Biological control is considered to be a more promising approach using bio-pesticides, predators as well as egg and larval parasitoids (APHIS, 2011). This study was undertaken to determine the efficacy of four insecticides, representing two groups of insecticide in the field and the host preference of the moth.

3.3 Materials and Method

3.3.1 Study locations

The study was conducted in Morogoro municipality and Mvomero (Mlali and Dakawa) to assess the host preference and control of *T. absoluta* in tomato cultivation by application of the four insecticides. The selected areas were chosen because they represent three major vegetable production areas in Morogoro.

12 plots of 5 m x 10 m were established and planted with tomato seedlings. The plants received all normal agricultural practices throughout the two growing seasons. Four plots per location were established in each location a distance of 1 km or more was used as means of isolation from one plot to the other to prevent interaction. The four plots acted as the focal point for the survey on the moth’s host preference.

3.3.2 Determination of efficacy of synthetic and bio-pesticides

Insecticides applied were Wiltigo (10 g/ 20 litre), combination of Antario (20 g/15 litre) and Recharge (75 g/15 litre), and a combination of Biotrine (10 g/15 litre) and Recharge (75 g/15 litre) the treatments were applied once a week. Antario and Biotrine are foliar sprayed while Recharge was applied on the soil. The control plots were left without any treatment except the normal agricultural practices. Efficacy of the insecticides was assessed by using delta traps loaded with pheromone lures.

3.3.3 Establishment of host preference of *Tuta absoluta*

The survey for host preference of *T. absoluta* in three locations in Morogoro municipality, Mvomero district (Mlali and Dakawa) from January 2017 to April 2017 (Table 2). Suspected cultivated vegetable crops as shown in Table 2 with observed symptoms of *T. absoluta* infestation were collected from the field and reared in the insectarium at the Sokoine University of Agriculture main campus in Morogoro.

Table 2: Location and suspected host plants for *T. absoluta* host preference survey.

Location	**Altitude (m)**	**Latitude/ Longitude**	**Host**
Morogoro Municipality	**487**	S06^0 47’ 34.9” E037^0 38’ 04.2”	Eggplant (*S. melongena*) Amaranthus (*A. retroflexus*) African eggplant (*S. aethiopicum*) Tomato (*S. lycopersium* L.)
Dakawa	**350**	S06^0 26’ 08.8” E037^0 32’ 04.0”	
Mlali	**572**	S06^0 57’ 40.6” E037^0 32’ 08.1”	

Earmarked symptoms of infestation of the moth on the host plants included mines between the upper and lower leaf surfaces resulting in clear patches that are often partially filled with frass (Roditakis *et al.*, 2010).

3.3.4 Sample collection and moth rearing

Samples collected from the host plants were leaves showing signs of *T. absoluta* infestation. The leaves were collected and placed in plastic containers with sand for rearing. Sample containers with the collected plant leaves as food source for the emerged insects were kept at room temperature for 2 weeks. The emerged insects were kept in the rearing containers for a week after emergence. They were then identified using the key by

Passoa and Young (2007). Identified adult moths were counted and recorded along with other insects that also emerged.

3.3.5 Data analysis

One-way ANOVA was run on the number of moth trapped by the delta trap with the insecticides as treatments and the location as blocks. For the host preference, the host constituted the treatment and location as the blocks. The Turkey's test was used for comparing the means of the number of trapped and emerged adult moths.

3.4 Results

3.4.1 Host preference on *Tuta absoluta* distribution

The number of *T. absoluta* moths that emerged from the collected host samples differed significantly between the host plants ($F_{(3)}$ = 49.9632, P = 2.20e^{-16}). Highest populations were recorded on Tomato plants. The least affected host was Amaranthus. The blocking effect which were the locations also showed significant variations ($F_{(2)}$= 5.45, P = 0.004981). Populations of adult moths differed significantly between hosts in Mlali ($F_{(3)}$= 29.28, P = 8.69e^{-12}).

The post hoc test according to Tukey's HSD showed significantly higher populations in tomato plants in Mlali (P<0.001) (Fig. 6). Adult Tuta moths also significantly varied between hosts in Dakawa ($F_{(3)}$= 45.09, P = 3.6e^{-15}). Host preference was highest in Tomato plants (Fig. 7). In Morogoro, the pattern of population was significant different between hosts was also significant ($F_{(3)}$= 8.647, P = 0.0000742). Post hoc test (Tukeys' HSD) showed that number of adult moths infesting tomato fields is similar to that infesting eggplants (P= 0.193). However, populations in tomato were much higher compared to those in the rest of the hosts (Fig. 8).

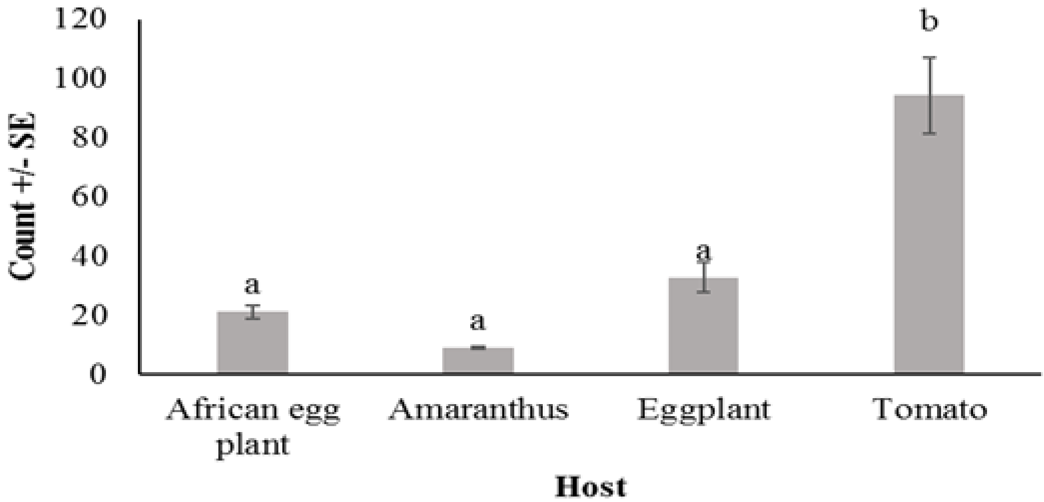

Figure 6: Mean (±SE) count of Tuta absoluta moth in different hosts in Mlali.

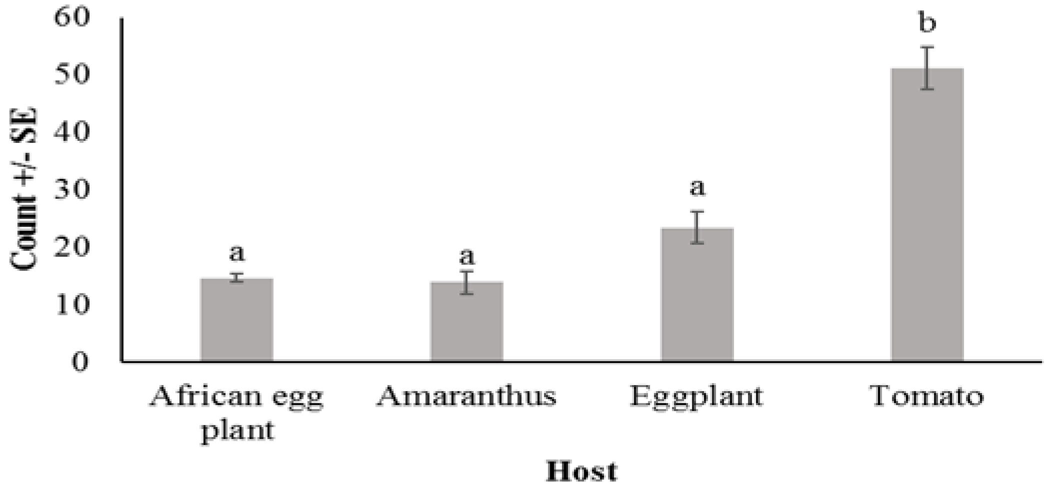

Figure 7: ***Mean (±SE) count of*** **Tuta absoluta** ***moth in different hosts in Dakawa.***

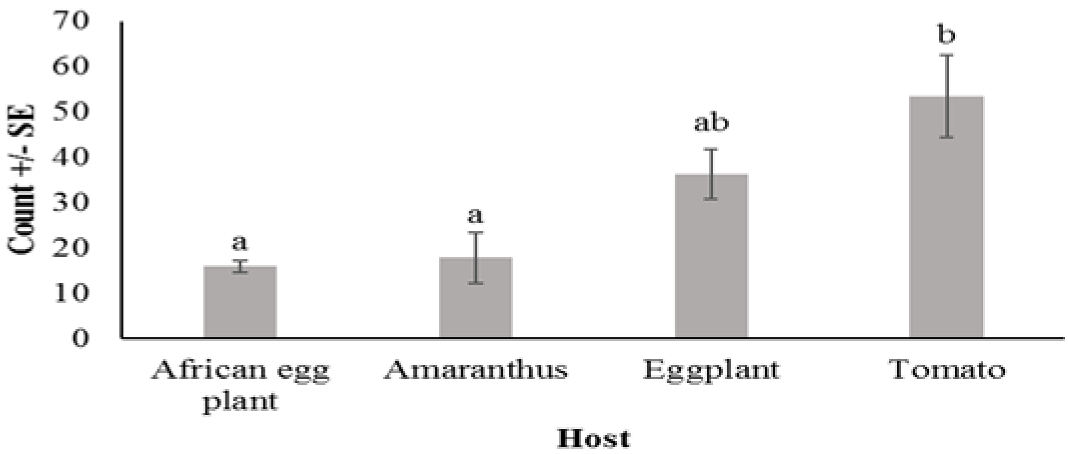

Figure 8: Mean (±SE) count of *Tuta absoluta* moth in different hosts in Morogoro.

3.4.2 Efficacy of applied treatments on the population of *Tuta absoluta*

In the first season, no significant differences between treatments ($F_{(2)}$ = 0.38, P= 0.768) was observed between the bio-pesticide and synthetic insecticide regarding the counts of *Tuta absoluta* moths. The blocking effect based on the locations Mlali (572 m asl), Dakawa (380 m asl) and Morogoro municipality (450 m asl) was also not significant ($F_{(2)}$ = 71.4, P= 0.076).

During the second season, the location effect was significant ($F_{(2)}$ = 4.079, P= 0.01901). Populations of the trapped male *Tuta absoluta* did not differ significantly across insecticide treatments at Morogoro ($F_{(3)}$=5.32, P = 0.824) and Dakawa ($F_{(3)}$ =1.25, P = 0.301). In Mlali, there was a significant difference in population levels of the moths ($F_{(3)}$= 5.323, P = 0.003226). The difference in pest populations observed between untreated plots (131.5 mean population of moth per plot) and in treated plots with Antario (67.5 mean population of moth per plot) was highly significant (P= 0.0039) as per Tukeys' HSD post hoc test. The mean separation also demonstrated that application of either synthetic or bio-pesticide is significantly effective in controlling the moth population (Fig 9).

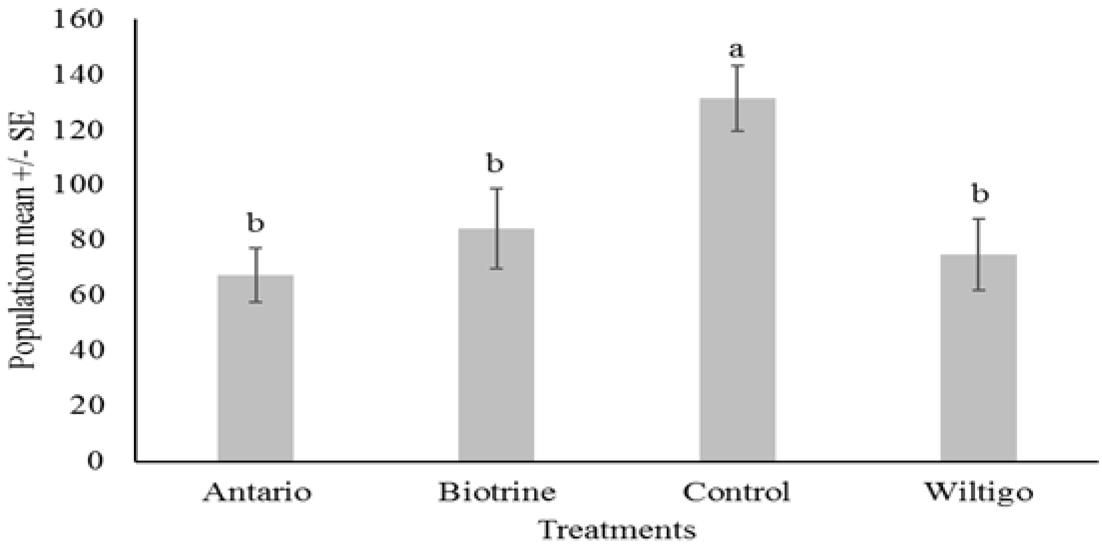

Figure 9: Mean (±SE) count of *Tuta absoluta* moth against applied treatments in Mlali in the 2nd growing season.

3.5 Discussion

Results of the first growing season applied insecticides showed that both the synthetic and bio-pesticides at the recommended rates and frequency are equally effective in controlling the moth in tomato cultivation. Applications of the insecticides were effective enough to protect the tomato plants and reduce damage by the moth.

For the second growing season the plot in Mlali applied with a combination of Antario and recharge was observed to have a lower moth population compared to the rest. Antario is a biorational solution for *T. absoluta* controlling the moth through two synergistic modes of action that works to protect the crop with its dual impact on the inner and outer layers of the leaves. While the recharge microbial formulation attacks over-wintering pupae dwelling in the soil.

It was observed that the control plots in Dakawa and Morogoro had lower population of trapped moths compared to that of Mlali. This could be attributed to the location and the surrounding plants present, for the plot in Dakawa it was located near a rice field and that of Morogoro was in a field mainly growing Cassava. Thus, providing an environment with minimal presence of suitable or known host for the moth. On the other hand, the plot in Mlali which had the highest moth population for both growing seasons, most of the fields are used to grow plants known to be hosts to the moth, including tomato and eggplants.

In respect to host preference the survey indicated that eggplant is the second most preferred host plant by the moth to Tomato. Moth emergence was assessed for a single generation, starting with infested leaves of a known and suspected host plants. The influence of the food reserve used and the development times of the moth on the specific food reserve used was thus not considered.

The results showed that Amaranthus and the African eggplant were the least preferred host plants among the four evaluated vegetables. Due to the low preference of the moth to the two host plants compared to tomato as observed by Addante *et al.,* (2014). These findings provided a clear understanding on the ability of the moth to complete its life cycle in not only tomato but also other numerous host plants. Agreeing with the findings by Mohamed *et al.,* (2015) that larvae of *Tuta absoluta* can complete its life cycle in eggplant leaves or fruits.

Eggplant was observed to be the best alternative crop compared to the African eggplant and Amaranthus for having a high moth emergence counts. The number of emerging moth per sample collected was lower in Morogoro municipality compared to Mlali per sample collected, with the highest number of moths observed in Mlali. The high number of moth capture is due to the high availability of preferred vegetable in Mlali compared to that of Morogoro Municipality.

Tomato, eggplant, African eggplant belong to Solanaceous family while Amaranthus belongs to the family Amaranthaceae. Thus, it is evident that *T. absoluta* is more than capable of completing its life cycle in other plant other than plants in the family Solanaceous and Fabaceae. Thus, control measures for the moth should encompass the presence of preferred host plants surrounding the cultivation sites.

Further surveys should be conducted on weeds and other vegetable crops. For identification of these host plants can facilitate management strategies for the moth, acting as a part of the control measure to deter the development cycle of the moth by reducing the availability of host plants for them to complete their life cycle (Bawin *et al*., 2015). In so doing reducing the year-round presence and their overall population in the cultivating areas. Surveys on weeds present in and around cultivation sites will provide more information on the weeds that can be used as host plants by the moths.

3.6 CONCLUSION

The study has shown that *T. absoluta* has the capability to use other plant families as host plants other than Solanaceae plants. Allowing continuous presence of the moth throughout the year in the absence of Tomato which is the most preferred crop followed by eggplant, African eggplant and lastly Amaranthus. Identification of the host range of the moth is important part in the development of efficient control strategies for the moth.

This study has confirmed that bio-insecticides may serve as a reliable control measure for *T. absoluta* in cultivation of Tomato in the country. Because they possess a similar efficacy as that of the once believed to be associated with synthetic insecticides. The most efficacious insecticide is the combination of Antario (20 g/15 l) and Recharge (75 g/15 l). The advantage of bio-insecticides is that they are highly bio-degradable and will facilitate the move to organic farming and sustainable pest management strategies.

REFERENCES

Addante, R., Baetan, R., Macavei, L., Oltean, I., and Porcelli, F. (2014). Host plants preferred by *Tuta absoluta* (Meyrick, 1917) larvae for pupation. Lucrari Stiintifice – vol. 57 (1) 281-282.

Bawin, T., Dujeu, D., De Backer, L., Fauconnier, M. L., Lognay, G., Delaplace, P., and Verheggen, F. J. (2015). Could alternative solanaceous hosts act as refuges for the tomato leafminer, Tuta absoluta. Arthropod-Plant Interactions, 9(4), 425-435.

Chidege, M., Al-zaidi, S., Hassan, N., Julie, A., Kaaya, E., & Mrogoro, S. (2016). First record of tomato leaf miner *Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae) in Tanzania. Agriculture & Food Security, 5(1); 17.

Desneux, N., Wajnberg, E., Wyckhuys, K. A., Burgio, G., Arpaia, S., Narváez-Vasquez, C. A., and Pizzol, J. (2010). Biological invasion of European tomato crops by *Tuta absoluta*: ecology, geographic expansion and prospects for biological control. *Journal of pest science*, 83(3), 197-215.

EPPO (European and Mediterranean Plant Protection Organization). (2009). *Tuta absoluta* found on Phaseolus vulgaris in Sicilia (IT). EPPO Reporting Service 8, 3.

Megido, R. C., Haubruge, E., and Verheggen, F. J. (2013). Pheromone-based management strategies to control the tomato leafminer, Tuta absoluta (Lepidoptera: Gelechiidae). A review/Synthèse bibliographique: les stratégies de lutte phéromonale utilisées pour contrôler la mineuse de la tomate, Tuta absoluta (Lepidoptera: Gelechiidae). Biotechnologie, Agronomie, Société et Environnement, 17(3), 475.

Mahmoud, M. E. E., Mohamed, E. S. I., Elhaj, M. A. M., Mohamed, S. A., and Ekesi, S. (2015). Host plants record for tomato leaf miner Tuta absoluta (Meyrick) in Sudan. EPPO Bulletin, 45(1), 108-111.

Passoa, S., & Young, J. (2007). Key to Separate Native and Quarantine Significant Species of Gelechiidae Feeding on Solanaceae In Florida And The Gulf Coast Region.

Pfeiffer, D. G., Muniappan, R., Sall, D., Diatta, P., Diongue, A., & Dieng, E. O. (2013). First record of *Tuta absoluta* (Lepidoptera: Gelechiidae) in Senegal. *Florida Entomologist*, 96(2), 661-662.

Roditakis, E., Papachristos, D., & Roditakis, N. E. (2010). Current status of the tomato leafminer *Tuta absoluta* in Greece. EPPO *bulletin*, 40(1), 163-166.

Sanga, A., and Mgimba, C. (2016). An Analysis Of Constraints That Affect Smallholder Farmers In The Marketing Of Tomatoes In Mbeya Urban And Peri-Urban, Tanzania. *Imperial Journal of Interdisciplinary Research*, *2*(3); 2454 -1362.

Shehata, S. (2016). Suitability of some insecticides for controlling the tomato leaf miner, Tuta absoluta (Meyrick). Research Journal of Pharmaceutical, Biological and Chemical Sciences. Accessed from [https://www. researchgate.net/publication/303923080] cited on 16/11/2017

Siqueira H.A., Guedes R.N. and Picanço M.C., (2000). Insecticide resistance in populations of Tuta absoluta (Lep., Gelechiidae). *Agricultural and Forest Entomology*., 2(2); 147-153.

Siqueira H.A., Guedes R.N., Fragoso D.B. and Magalhaes L.C., (2001). Abamectin resistance and synergism in Brazilian populations of *Tuta absoluta* (Meyrick) (Lep., Gelechiidae). *International Journal of Pest Management*., 47(4); 247-251.

CHAPTER FOUR

4.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

i. The study has shown that *Tuta absoluta* is ever present in all locations commonly used for cultivation of tomato. Its presence however varies with some areas having a higher population than others.

ii. *Tuta absoluta* is capable of completing its life cycle in not only tomato but also Egg plants, African eggplant and Amaranthus.

iii. The difference in the locations altitude was observed to have an influence on the population dynamics of the moth.

iv. The treatment used showed that they were all equally capable to manage the moth population. The ability of the synthetic insecticides is at an equal strength to that of the bio-insecticides.

v. Tomato was observed to be the most preferred host plant of the moth followed by Egg plants, African eggplant and Amaranthus.

4.2 Recommendations

i. More surveys should be conducted to determine the extent of the host plants for the moth on both crops and weeds. So as to have an extensive record of the most preferred alternative hosts.

ii. The influence of temperature and rainfall on the population of the moth, rate of dispersion and reproduction requires further studies to determine the degree of influence it has on the population and development of the moth.

iii. Proper use, handling and storage of bio-pesticide training to the farmers is required.

iv. Bio-pesticides like Antario, Biotrine and Recharge have the same capability to control the moth they should be highly recommended to farmers so as to reduce use of synthetic pesticides, which has tendencies to have adverse impact to the environment. They also have adverse effects on non-targeted species and may result in the development of insect resistance and resurgence.

v. It is of great importance to continue monitoring the moth abundance, distribution and its development cycles across all agro-ecological zones used for Tomato cultivation. So as to develop useful information on the moth to be used to develop sustainable management strategies