DIVERSITY, DISTRIBUTION AND HOST PREFERENCE OF CUCURBIT INFESTING FLIES (DIPTERA: TEPHRITIDAE) IN MOROGORO, EASTERN-CENTRAL TANZANIA.

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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.

2021

EXTENDED ABSTRACT

Accessibility to safe, nutritious and healthy fruits and vegetables is essential for maintaining an active life and critical for the survival of all people. The demand for high quality fruits and vegetables has been growing considerably in developing countries for the past few years. Such higher demand has created a new lucrative trade opportunity for fruits and vegetables. In addition to increased liberal trade arrangements and people movement between countries, the international trade of fruit and vegetables has resulted into introduction of exotic plant pests of quarantine importance including fruit flies (Diptera: Tephritidae) in partner countries. Apart from the devastating damages caused by indigenous fruit flies, exotic fruit flies have also been causing tremendous loss in fruits and vegetables including cucurbit crops.

Previous studies indicated that cucurbit infesters vary in their diversity, infestation rates and distribution with geographical location and season. Presence of fruit flies in Morogoro region was initially reported by Mwatawala *et al*. (2006). However, the ecological structure (diversity, species composition and abundance) as well as host preference of cucurbit infesters in Tanzania remained largely unknown. A thoroughly understanding of ecological structures and host preference of fruit flies is a prerequisite if sustainable management programmes is to be formulated and deployed. Therefore, this study assessed the diversity and host preferences as well as spatial and temporal abundance of fruit flies infesting cucurbit crops in the Morogoro region.

Experiments were laid out in a full factorial design. Factors were seasons, agroecological zones, tapping weeks and fly species. Trapping of fruit flies was conducted from March to November 2020 in ten established cucurbit fields focusing on cucurbit infesting flies.

Tephri traps were baited with one of three different baits: Cue-Lure (CL), BioLure (BL) and Zingerone (ZN) to attract members of the genus *Dacus* and *Zeugodacus*. On other hand, a minimum of 10 fruits were also randomly collected from each plot during the peak of fruiting season followed the methodology described by Copeland *et al*. (2002). Fruits were transported to the rearing facility in the horticulture unit at Sokoine University of Agriculture (SUA) Morogoro. Emerged adults were removed and handled following methods described by White and Elson Harris (1994).

In total, 21 673 fruit fly specimens were collected and 22 146 flies emerged from reared fruits. The trapped specimens belonged to 19 species from three genera (Dacus, Zeugodacus and Bactrocera). Of the total specimens collected, *Zeugodacus cucurbitae* was the most dominant species and accounted for 83.4% of the total specimens collected. All of the remaining species constituted the remaining 16.6% of the total specimens. Results also showed significant differences in infestation rates among *Zeugodacus cucurbitae* (Coquillet), *Dacus vertebratus* Bezzi and *Dacus ciliatus* L. ($P<0.05$). The effects of host, altitude, season and fruit fly interactions on infestation rates were also significant ($P<0.05$). *Cucurbita maxima* was the most preferred host by *Z. cucurbitae* at all altitudes, *C. lanatus* was preferred host for *D. vertebratus* and *C. maxima* was the preferred host for *D. ciliatus* L. Incidence of *Z. cucurbitae* showed significant association with host crops ($P<0.05$). On other hand incidence of *D. vertebratus* showed significant association between host and altitude ($P<0.05$). Likewise, D. *ciliatus* incidence showed significant association between host, altitude and season (0.05).

The results from this study suggests that among the fruit fly species, *Zeugodacus cucurbitae, D. bivittatus, D. punctatifrons, D. vertebratus, D. ciliatus, D. telfaireae* and *B. dorsalis* represented the most devastating group of cucurbit infesters. Therefore, we recommend that, any management program should focus to suppress their population by considering the agroecological zones, crop phenology and growing season.

Key words: Species diversity, Host preference, Spatial and temporal abundance, Cucurbit crops, Infestation rate.

DECLARATION

I, PETRONILA P. TARIMO, do 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 concurrently being submitted in any other institution

____________________ ____________________

Petronila P. Tarimo Date

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The above declaration is confirmed by:

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Prof. Maulid W. Mwatawala Date

(Supervisor)

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ACKNOWLEDGEMENTS

First of all I thank the almighty God for blessing me with a good health, strength and the willpower to carry out this study.

I would like to express my sincere gratitude to my supervisor Prof. Maulid. W. Mwatawala for his encouragement, creative advice, proper guidance, constructive criticism and all forms of academic support towards the completion of this research work. May GOD be with him in everything he is determined to accomplish.

I sincerely thank the Belgian Directorate General for Development Co-operation (DGDC) through the fruit flies agroecology project (AGROVEG), collaboration between Sokoine University of Agriculture (SUA), Morogoro, Tanzania, Eduardo Mandlane University (EMU) of Maputo Mozambique and Royal Museum for Central Africa (RMCA), Tervuren, Belgium for providing me with financial support for this study.

I am thankful to Dr De Meyer (Royal Museum for Central Africa, Belgium) for confirmation of fruit flies identifications.

I sincerely appreciate the support and contributions provided by Dr Abdul Kudra, Dr Ramadhan Majubwa and Dr. Richard Madege as well as the entire academic community and staff from the Department of Crop science and Horticulture at SUA.

I would also like to extend my sincere thanks to my friend and colleague Mr. Sija A. Kabota for personally devoting his time in helping me in throughout this study and also those who devoted their time.

Lastly, I genuinely thank Mr. Exupery A. Chuwa, all my friends and classmates and those who in one way or the other supported me in all activities that facilitated in accomplishing this work.

DEDICATION

To my lovely parents Peter Silvano Mshai and Aloisia Baltazar Mrema who laid the foundation of my education and whose sincere love and support has continually inspired my life.

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LIST OF ABREVIATIONS AND SYMBOLS

%	per cent
<	less than
>	greater than
^{0}C	Degree Centigrade
ABE	Abundance-based Estimator
ACE	Abundance-based Coverage Estimator
ANOVA	Analysis of Variance
asl	above sea level
BL	BioLure
CABI	Commonwealth Agriculture Bureau International
CL	Cue lure
CM	Crop Museum
df	Degrees of Freedom
e.g.	for example
et al.	and others
Exp	Exponential
F	F- values
FAO	Food and Agriculture Organisation
HT	Horticulture Unit
i.e.,	that is
IAEA	International Atomic Energy Agency
KF	Kifuru
Kg	Kilogram
MF	Mafiga
MG	Mgola
MK	Mkumbulu

mm	Millimeters
MS	Morning Site
MZ	Mazimbu
pa	per annum
RMCA	Royal Museum for Central Africa
RV	Ruvuma
SAC	Species Accumulative Curves
SE	Standard error
SIT	Sterile Insect Technique
spp	Species
SUA	Sokoine University of Agriculture
SUGECO	Sokoine University Graduate Entrepreneurs Cooperative
TMA	Tanzania Meteorological Authority
UNICEF	United Nations International Children’s Emergency Fund
URT	United Republic of Tanzania
USD	United States Dollar
ZN	Zingerone

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Accessibility to safe, nutritious and healthy fruits and vegetables is essential for maintaining an active life and critical for the survival of all people. In the sub-Saharan Africa, the rate of fruits and vegetables consumption is low compared to the developed countries (Ruel *et al.,* 2005; UNICEF, 2019), this has doubled the burden of malnutrition and obesity to the local population (Onyango *et al.,* 2019). The demand for high quality fruits and vegetables in both developed and developing countries is growing considerably and this is often related increased awareness on the health benefits related to fruits and vegetables consumption (Ruel *et al.,* 2005). Increased liberal trade arrangements have created new lucrative trade opportunities for fruits and vegetables worldwide (Maelzer *et al.,* 2004). Such global trade opportunities have resulted into increased international trade for agricultural commodities to many parts of the sub-Saharan Africa. Apart from facilitating people's movement between countries, international trade has increased the risk of introducing exotic plant pests of quarantine importance between countries (Sequiera, 2002). Such introductions compromise the exportation and importation of plants and plant products from countries previously free of these quarantine pests but have experienced an introduction of such pests (Maelzer *et al.,* 2004).

Horticultural sector is defined as the growing of fruits, vegetables and ornamental plants (Tindal, 1987). It is the fastest growing agricultural sub-sector in Africa providing income and employment to majority of the people. The Sub-Saharan African horticultural industry, including Tanzania, is relatively smaller than the South American or Asian markets but has been growing considerably (FAO, 2006). Majorities of smallholder farmers in Sub-Saharan Africa earn their livelihoods from the horticulture sub-sector. These farmers produce fruits and vegetables mainly intended for local consumption in the local and urban markets and few are exported to neighboring countries (Lux, 1999). In Tanzania, fruits and vegetables including cucurbits are the main horticultural crops produced predominantly by small-scale farmers located in different agroecological zones, which support a variety of products (Kusolwa, 2003).

Cucurbitaceous vegetables are among the major crops cultivated throughout the world (Kadio *et al*., 2011). Like other vegetables, cucurbits are important in generating income and in providing nutrition and food security especially to the small-holder farmers in Tanzania (Mbega and Mabagala, 2012**)**. Major cucurbits grown in Tanzania include, cucumber (*Cucumis sativus* L.), watermelon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai), and Squash (*Cucurbita moscharta* D.). Most of these vegetable fruits are sold within Tanzania although a few are exported to the neighbouring countries (Mwatawala *et al.*, 2006). However, the horticulture sector particularly the production of fruits and vegetables is threatened by the ravages of biotic and abiotic factors. Amongst the various biotic factors that limit the production of fruits and vegetables are the fruit flies.

Fruit flies (Diptera: Tephritidae) are among the most devastating pests of many important fruits and vegetables including different species of cucurbit crops (Motswagole and Nyamukondiwa, 2019). High fruit and vegetable yield losses have been recorded in different part of the world. The great majority of these fruit flies belong to the genera *Anastrepha*, *Ceratitis*, *Zeugodacus*, *Dacus* and *Rhagoletis* (White and Elson-Harris, 1994). More than 35% of fruit fly species attack soft fruits of economic importance to majority of small holder farmers. They differ in their origin however; the most damaging species are of Asian origin which have invaded the African continent while few are of

Afrotropical origin. Among the Asian species are from the genus *Zeugodacus* particularly the species *Zeugodacus cucurbitae* (Coquillett) which is the major threat to cucurbit production worldwide (Dhillon *et al*., 2005). In contrast, African indigenous fruit flies of economic importance include but not limited to *Dacus ciliatus* Loew, *Dacus bivittatus* (Bigot), *Dacus veterbratus* Bezzi *and Dacus punctatifrons* Karsch.

1.1.1 Importance and constraints to production of cucurbitaceous vegetables

The Cucurbitaceae family commonly known as the gourd family is an excellent example of a plant family with many economically useful species (Ajuru and Nmom, 2017). They are native in most countries of the world, especially in the tropics, where they are cultivated in every country, state, and province. The Cucurbitaceae consists of many important food plants such as melon, pumpkin, squash, cucumber; useful plants for the production of items of utility such as bottle gourds, loofahs and ornamental gourds. Some species such as bitter melon, cucumber, musk melon, etc are considered to have medicinal properties due to the presence of cucurbitacins (Ajuru and Nmom, 2017). Others such as luffa, cucurbita, etc are used as complementary dietary ingredient of feed for poultry and increasingly as a protein and vitamin supplement to aqua feeds. Members of this family such as momordica (*Momordica charantia*), cucurbita (*Cucurbita pepo, Cucurbita andreana, Cucurbita ficifolia*) and cucumis (*Cucumis sativus* and *Cucumis melo*) are also used as remedies for livestock (Dhiman *et al.,* 2012). In addition, seed oil of melon is a source of biodiesel. Cucurbits have various uses including nutritional, medicinal, ethnoveterinary and ethnomedicinal value of these plants, as well as their uses as items of utility, complementary dietary ingredient for poultry and aquafeed and as a source of biodiesel (Ajuru and Nmom, 2017).

Cucurbits production is however constrained by various factors that include availability of seeds, access to markets, poor/lack of storage infrastructure, poor storage and transport infrastructure, poor marketing systems and inadequate knowledge about pest management (Neguwo, 2004). Cucurbit production is also threatened pests notably fruit flies. White and Elson-Harris (1994), White (2006) and CABI (2007) have listed most of the fruit flies of economic importance including those occurring in Afrotropical region.

1.1.2 Economic importance of fruit flies

Globally, out of the 4 257 fly species comprising the family of Tephritidae, about 1 400 species are known to develop in fruits. Out of these, about 250 species already are, or may become, pests by inflicting severe damage to fruits of economic value (Thompson, 1998). Direct fruit injury, fruit drop, decay by opportunistic pathogens, loss of lucrative export market through quarantine restrictions that are imposed by importing countries to prevent the introduction and spread of fruit flies are all mechanisms by which fruit fly infestations causes economic damage (Clarke *et al*., 2005).

Losses due to fruit flies are variable depending on species and location. In most cases monetary losses have not been determined. Thompson (1996) reported potential losses that would exceed A$100 million, if fruit flies were not controlled in Australia. Invasion of fruit flies in California was predicted to cause crop losses of up to USD 9 million (Thompson, 1996). The eradication of the Oriental fruit fly (*B. dorsalis*) from the south-western islands of Japan using the Sterile Male Technique (SIT) costed approximately USD 32 million- and 200 000-man days (White and Elson- Harris, 1994). Annual losses in the eastern Mediterranean (Israel, Palestinian Territories, Jordan) linked to fruit fly infestations are estimated at USD 192 million (Enkerlin and Mumford, 1997).

Pradhan (1976) reported 28.7 - 59.2, 24.7 - 40.0, 27.3 - 49.3, 19.4 - 22.1, and 0 - 26.2% yield losses in pumpkin, bitter gourd, bottle gourd (*L. siceraria*), cucumber, and sponge gourd, respectively, caused by *Z. cucurbitae* from the field experiments on assessment of losses caused by cucurbit fruit fly conducted in Nepal. Dhillon *et al*. (2005) reported losses that vary between 30% and 100%, depending on the cucurbit species and environmental conditions. Sapkota *et al*. (2010) reported losses of up to 50% losses in squash yield caused by *Z. cucurbitae* in farmers' fields in Nepal without control measures.

1.2 Major Fruit Flies Attacking Cucurbits

1.2.1 Description and distribution

Tephritidae are one of the most devastating crop pests occupying a prime position of quarantine pests in the world. Ekesi (2010) reported that Sub-Saharan Africa is the aboriginal home to 915 fruit fly species from 148 genera, of which 299 species develop on wild or cultivated fruit or both. Highly damaging fruit flies belong to three genera: *Ceratitis*, *Dacus* and *Trirhithrum* (White and Elson-Harris, 1994). Ekesi and Billah (2007) listed *Dacus* species such as *D. bivittatus*, *D. ciliatus*, *D. puntatifrons*, *Dacus frontalis* Becker and *D. vertebratus* which belong to the tribe Dacini as some of major endemic species causing considerable crop losses in cucurbitaceae.

1.2.1.1 *Zeugodacus cucurbitae* (coquillett)

The melon fly, *Z. cucurbitae* attacks 125 host plants mostly from family Cucurbitaceae and some Solanaceae. Melons (*Cucumis melo*), cantaloupe (*C. melo cantalupensis*), cucumber (*Cucumis sativus*), pumpkin (*Cucurbita maxima*), squash (*Cucurbita pepo*) and eggplant (*Solanum melongena* L.) are among its preferred cultivated hosts (Christenson and Foote, 1960). This species is distributed in some parts of Africa, the Middle East, Southeast Asia, Micronesia and Hawaii with India considered as its native home. The first African records date back to 1930 (Munro, 1984).

The scutum is predominantly red to brown in colour. The postpronotal lobe is entirely pale yellow or orange. Its scutum has parallel sided lateral postsutural yellow or orange vittae which extend forward to suture and backwards to level of the intra-alar setae. It has medial vitta which do not extend towards the anterior to suture. The scutellum is yellow except for narrow basal band. The wing has a complete costal band stretching to below R2+3 and sometimes reaching R4+5. The costal band expands into a spot at the wing apex which extends about half way towards M. It has an anal streak.

1.2.1.2 *Dacus ciliatus* (loew)

This species attacks almost all species of Cucurbitaceae (White and Elson-Harris, 1994) as well as tomato (*Lycopersicon esculentum* Miller), beans (*Phaseolus vulgaris*), cotton (*Gossypium* sp.) and okra (*Abelmoschus esculentus*). The adult fly is easily recognised by being a predominantly orange species with facial spots, 2 scutellar setae and a yellow spot covering most of the katatergite. It has an orange anatergite. The mid femur is yellow or orange to yellow with the wing having a coastal band that is expanded apically to form an apical spot. Its scutum has no yellow stripes but the anterior supra-alar setae and prescutellar acrostichal setae are present (White and Elson-Harris, 1994).

1.2.1.3 *Dacus bivittatus* (bigot)

The two spotted pumpkin fly, *D. bivittatus*, is one of the most common and widespread *Dacus* species pest for cucurbits with its males attracted to cue lure. *Dacus bivittatus* major cucurbit host range includes watermelon (*C. lunatus*), squash (*C. maxima*), cucumber (*C. sativus*), cantaloupe (*C. melo cantalupensis*) while other hosts include but not limited to pumpkin (*C. pepo*), papaya (*Carica papaya*), tomato (*L. esculentum*) and coffee (*Coffee* sp.). The adult fly is predominantly dark orange to red-brown with facial spots. Its scutum has lateral and medial yellow stripes with an anterior supra-alar seta, 2 scutellar setae and no prescutellar acrostichal setae. The wing has a very broad coastal band from base to apex. This species is known to occur throughout Africa and its males are attracted to cue lure (White and Elson-Harris, 1994).

1.2.1.4 *Dacus punctatifrons* (kirsch)

Dacus punctatifrons is widespread in several African countries, Indian Ocean and Middle East. It attacks a wide range of Cucurbitaceae but has also been reared from tomato and wild watermelon (*Passiflora foetida* Linn.) (White, 2006). The fly is predominantly orange-brown species with facial spots. Its scutum has a medial black stripe or predominantly black with lateral and medial yellow stripes. It has a pair of scutellar setae and an anterior supra-alar seta. Both anatergite and katatergite are largely covered by a single yellow stripe. The wing has cross-vein r-m sometimes covered with an infuscate mark. The male has a pecten. It has no prescutellar acrostichal setae. Males are attracted to cue lure (White and Elson-Harris, 1994).

1.2.1.5 *Dacus vertebratus* (bezzi)

This species differs from *D. ciliatus* by having the laterotergal xanthine across the anatergite as well as katatergite (White, 2006). It is a pest of cucurbits with a strong preference for watermelon (*C. lunatus*) although it has been recorded on other cucurbits such as cantaloupe (*C. melo cantalupensis*), cucumber (*C. sativus*), squash (*C. maxima*). It is found throughout Africa, in the Middle East and Islands of the Indian Ocean. Males are uniquely attracted to vert lure (White and Elson-Harris, 1994).

1.2.2 Abundance and population dynamics of fruit flies of cucurbits

Laskar and Chatterjee (2010) determined the influence of abiotic factors such as temperature, humidity and rainfall to investigate population fluctuation of *Z. cucurbitae* in India. They found that during warm and rainy months the flies were more active as compared to that of dry and winter months. Significant positive correlation of fly incidence was noted with minimum and maximum temperature, whereas temperature gradient correlated negatively with fly incidence. Negative correlation of fly incidence was also recorded with maximum humidity and humidity gradient and positive with the minimum.

Kumar *et al*. (2006) determined the relative incidence of *Z. cucurbitae* and *D. ciliatus* on cucurbitaceous vegetables from June 2002 to October 2003 by fruit collection and male trap captured. Traps baited with cue lure and malathion captured *Z. cucurbitae* throughout the study period. Peak catches of *Z. cucurbitae* were recorded in August 2002 to September 2003 with 14.14 and 11.14/trap/week respectively while December recorded the lowest catch. Mean numbers for *D. ciliatus* trapped from May to October was around 1/trap/week. Furthermore, number of *Z. cucurbitae* showed a significant positive correlation with mean weekly relative humidity.

1.3 Justification of the study

Fruit flies are a major threat to production and marketability of fruits and vegetables particulary in Tanzania. They are widely distributed in many parts of Tanzania, inflicting heave losess to both wild and cucltivated fruits and vegatables (Mwatawala *et al*., 2009). According to Mwatawala *et al.* (2005), smallholder farmers in Tanzania might be suffering from high losses and also the export potential of fruits from Tanzania may be threatened by fruit flies. Therefore, much information is needed before management programmes can be formulated to help the smallholder farmers in Tanzania including an inventory of fruit flies in different agro-ecological zones (Mwatawala *et al.*, 2005). Morogoro region in Tanzania provides horticultural products for major towns like Dar es Salaam and Dodoma [United Republic of Tanzania (URT) 2002]. Although a lot of work has been done on fruit flies particularly detection, distribution and dynamics of fruit flies in many parts of Tanzania, little is known about the diversity and abundance of fruit fly species infesting cucurbits in Morogoro region. A study by Mwatawala *et al.* (2015b), established preference of Z. cucurbitae among three hosts, watermelon, cucumber and squash. This study did not include other cucurbit infesting flies. Moreover, a study by Mkinga *et al*. (2015), determined developmental biology of *Z. cucurbitae* in three cucurbitaceous hosts. This study was conducted in laboratory and was limited to one species only. Furthermore, a study by Mwatawala *et al.* (2006) on seasonality and host utilization did not include biolure and Zingerone.

Due to limited studies on cucurbit infesting flies in Morogoro region and Tanzania in general, their spatial and temporal fluctuation and the damage caused to cucurbit production have also remained largely unknown. The distribution of cucurbit infesers is not well known, their diversity and abundance pattern have not been well established. The host preference of cucurbit infesters has not been well established across different agro ecological zones in Tanzania. Therefore the results of this study aims to provide important ecological parameters and basic information necessary for the development of an agro-ecological fruit fly control programme in cucurbit farming systems.

1.4 Objectives

1.4.1 Overall objective

Establishing climatic and host niche among cucurbit attacking fruit fly species in Morogoro, Tanzania.

1.4.2 Specific objectives

i. To assess the diversity of cucurbit infesting flies in different agroecological locations of Morogoro.
ii. To describe the seasonal abundance of fruit flies in cucurbitaceous production systems
iii. To evaluate the host use preference of fruit flies in cucurbits.

1.5 Organization of Dissertation

This dissertation is developed in publishable manuscripts format comprising of five main chapters. Chapter one is the general introduction, chapter two, three and four consist of the publishable manuscripts and chapter five is a general conclusion and recommendations.

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CHAPTER TWO

Diversity of cucurbit infesting flies (Diptera: Tephritidae) in agroecological locations of Morogoro, Eastern-Central Tanzania

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To be submitted to: Journal of Insect Science (OXFORD)

2.1 Abstract

Cucurbit crops are important source of income and nutrition to many of small-scale farmers in Tanzania. Infestation by fruit flies curtail the production of these crops. Little was known about the diversity of fruit flies in cucurbit production systems prior to this study. Therefore, this study investigated the diversity of cucurbit infesting flies across the two agroecological zones of the Morogoro region from March to November 2020. Baits (Cue Lure, Zingerone and Biolure) were used to trap the fruit fly species in ten established cucurbit fields. Data were collected weekly for eight weeks in each of the three seasons (March to May 2020, June to August 2020, and September to November 2020). Both alpha and beta diversity was determined using nonparametric indices. Species Accumulative curve was only used to determine the sampling effort. Results indicated that the sampling efforts was sufficient to caught more than 78% species at each field. A total of 21673 flies belonging to 3 genera and 21 species were identified. Out of three genera, *Zeugodacus* (78.86%) was the most dominant genera according to total number of individuals, followed by *Dacus* (15.45%) and *Bactrocera* (0.05%). 77.58% of the individuals were collected from the Mountainous zone while the remaining 22.42% were collected from the Plateau zone. These results are significant for the decision-making process for effective monitoring and management of cucurbit infesters in the Morogoro region. Our field data contribute in important ways to basic knowledge of biodiversity of fruit flies and constitute baseline data for implementation of in Integrated Pest Management.

Keywords: Species diversity, fruit flies, Cucurbit crops

2.2 Introduction

Cucurbitaceous vegetables are among the major important vegetable fruits cultivated throughout the world (Kadio *et al*., 2011). Like other vegetables, cucurbits are important source of income and nutrition to majority of small-holder farmers in Tanzania (Mbega and Mabagala, 2012**)**. The major cucurbits grown in Tanzania include, cucumber (*Cucumis sativus* L.), watermelon (*Citrullus lanatus* (Thunb.) Matsum and Nakai), and Squash (*Cucurbita moscharta* D.) and pumpkins (*Cucurbita pepo* L.). Most of these vegetable and fruits are sold within Tanzania although a few are exported to the neighbouring countries (Mwatawala *et al.,* 2006).

The capacity of local and international markets for cucurbits have been growing considerably for the last decade and it is often related to an increase in awareness on health benefits related to eating fruits and vegetables, thus securing these markets for cucurbits requires cucurbits produce that are free from pests and diseases (Mwatawala *et al.,* 2006). However, since the onset of fruit fly infestations in Tanzania, the production of cucurbit crops has been hampered by fruit flies thus becoming one of major constrains for cucurbits production.

Fruit flies being among the most devastating pests of many important fruits and vegetables including different species of cucurbit crops (Motswagole and Nyamukondiwa, 2019), tremendous losses have been recorded in different part of Tanzania. Literatures indicated that there are about 200 most damaging species of fruit flies distributed throughout the world (Gnanvossou *et al.,* 2017). These species inflict high yield losses and influence marketability of many economic important fruits and vegetables including cucurbits (Sarwar *et al.,* 2013). The annual economic damage on fruits and vegetables due to fruit flies have been estimated to be up to US $ 42 million in Africa and US $1billion worldwide (Motswagole and Nyamukondiwa, 2019).

The damaging potential of fruit flies varies between cucurbit species, geographical location and fly species (De Meyer *et al.*, 2010). For instance, in Africa, several native (*Ceratitis* and *Dacus*) and exotic (*Bactrocera* and *Zeugodacus*) species inflict considerable losses ranging from 30-90% (Badii *et al*., 2015) and up to 100% in unprotected cucurbit crops (Gnanvossou *et al.*, 2017). The most destructive fruit fly species for cucurbit crops belong to the genera *Dacus* and Zeugodacus (Motswagole and Nyamukondiwa, 2019). Apart from being detected in Morogoro and inflicting high yield losses in cucurbit crops, the biodiversity of Zeugodacus and Dacus species have remained largely unknown making their control difficult as most of them have a wide host range. Only few studies have established the biodiversity of cucurbit infesters. For instance, a study Mokam *et al.* (2014), established the pattern of species richness of cucurbit infesters in domesticated cucurbit crops while Mwatawla *et al*. (2006) established the biodiversity of fruit flies in different fruits but did not focus on cucurbit crops. Given the economic importance of cucurbits and the losses incurred by fruit fly infestations, an effective control measure for these pests requires a thorough understanding of their population dynamics and climatic preferences. The study sought to provide necessary data for practical management strategies of fruit flies infesting cucurbits in different agroecological zones of Morogoro.

2.3 Materials and Methods

2.3.1 Study site

Studies on the diversity of cucurbit infesting flies were conducted from March to November 2020 in Morogoro Region in eastern-central Tanzania. Morogoro Region is located in the transition zone between the bimodal and unimodal rainfall belts at S5°58’- S10°0’South and E35°25’- E38°30’ East (URT, 2002). Study sites were selected between October and November 2019 within plateau and mountainous zones of Morogoro (Table 2.1). River valley and basins zone was excluded because of dominance of flooded paddy fields.

Table 2.1: Agroecological zones of Morogoro Region

Zone	**Characteristics**
Mountainous zone	Altitude: > 600 meters asl; Average rainfall: 800 mm – 2500 mm p.a
Plateau	Altitude: 300-600 meters asl; Average rainfall: 700 mm – 1200 mm p.a
River valleys and basins	Altitude: < 300 meters asl; Average rainfall: 900 mm – 1400 mm p.a

Source: URT 2002.

Ten experimental plots were established in ten different localities within two agroecological zones namely, the plateau and mountainous zones of Morogoro (Table 2.2). In each agroecological zone five experimental plots located at least 1 km apart from each other were established. Selected hosts were cucumber (*C. sativus*), variety “Ashley”, and watermelon (*C. lanatus*), variety “Sugar baby” and squash (*C. maxima*) variety “Waltham”. Cucumber, watermelon and squash were each planted on a 0.25-acre (1012 m^2) plot at a spacing of 50 cm x 60 cm, 1 m × 1.5 m and 1 m × 1.5 m respectively.

Table 2.2: Experimental field locations in two agroecological zones of Morogoro.

Location of field plots in two different Agroecological zones			
Location	**Coordinates**	**Altitude**	
SUA Horticulture Unit (HT)	S06˚50'41.4" E37˚39'43.3"	524 m	**Plateau zone**
SUA Crop Museum (CM)	S06˚51'00.53" E37˚39'17.90"	528 m	
SUGECO (SG)	S06˚50'22" E37˚38'42.2"	511 m	
SUA Mazimbu (MZ)	S06˚47'26.208" E37˚38'7.926"	486 m	
SUA Mafiga (MF)	S06˚50'22.764" E37˚37'53.46"	503 m	
Morning Site (MS)	S06˚53'17.9" E37˚40'14.93"	1274 m	**Mountainous zone**
Mkumbulu (MK)	S06˚52'24.2" E37˚40'21.5"	1105 m	
Ruvuma (RV)	S06˚52'34.6" E37˚40'3.7"	995 m	
Kifuru (KF)	S06˚53'32.1" E37˚40'9.5"	1418 m	
Mgola (MG)	S06˚51'41.4" E37˚40'4.3"	1084 m	

2.3.2 Baits and trapping

Trapping was conducted from March to November 2020 in ten established cucurbit fields focusing on cucurbit infesting flies. Tephri traps were baited with one of three different baits Cue-lure (CL), Zingerone (ZN) and BioLure (BL, containing putrescine, trimethylamine and ammonium acetate) to attract members of the genera *Dacus* and *Zeugodacus*. CL and ZN are male specific while BL attracts flies of both sexes. Zingerone was available in crystalline form, which was melted at 40°C in a glass beaker using heated bath method (Manrakhan *et al*., 2017; Inskeep *et al*., 2018). Once liquid, ZN was applied with a graduated pipette to individual 1 x 3 cm cotton dental wicks (Royer, 2015). CL was available as a plug while BL was supplied in a sachet. Traps were set following guidelines by IAEA (2003). Three traps each baited with one attractant were placed on tree branches or held on wooden poles at a height of 1.5 m above the ground at least 30 m apart from each other. A strip of an insecticide dichlorvos (DDVP) placed at the bottom of each trap to kill trapped insects. Sticky glue (Tanglefoot) was applied at the base of branches or poles where to prevent ants from accessing traps. Traps were inspected once a week, and catches were placed in vials marked with unique numbers corresponding to a data sheet with details on date, location and lure. In order to minimize location bias traps were rotated clockwise after each inspection. Attractants and insecticide strips were replaced every four weeks. Collected specimen were transported to the entomology laboratory at the Sokoine University of Agriculture (SUA) and preserved in 70% ethanol prior to sorting and identification.

2.3.3 Data collection and identification

Data were entered as number of fruit flies per trap per day (FTD). Fruit fly morphological identification to species level was conducted at SUA entomology laboratory with the aid of binocular stereomicroscope using keys and characters presented by White and Elson-Harris (1994), White (2006), Ekesi and Billah (2007) and electronic keys by Virgilio *et al*. (2014). For further identification and confirmation some specimens were sent to the Royal Museum for Central Africa (RMCA).

2.3.4 Statistical analysis

Fruit fly trapping data were organized using Microsoft excel before being subjected for analyses. Sampling efforts in each locality was evaluated using three non-parametric abundance-based Estimators (ABE) (Abundance-based Coverage Estimator ACE, Chao 1, and Jackknife 1) following the protocol descried by Chao and Shen, (2004). These estimators were performed using EstimateS software version 9.1.0 (Colwell 2013) to estimate the sampling efforts required to obtain the minimum number of fruit fly species from each field.

The alpha diversity of cucurbit infesting flies based on both rare and common (dominant) species was estimated using Shanon-Wiener diversity index, Simpson index as well as evenness index of Pielou calculated to estimate the equitability component of diversity while Margalef index was employed to highlight the most species-rich fields. These indices account for both abundance of the species present (richness) and how close in numbers each species is in an environment (evenness). The indices were determined as;

i. Shannon diversity index (Shanon-Wiener, 1949) (H´ $= -\sum_{i=1}^{S} \frac{¿}{N} \ln \frac{\mathrm{ni}}{\mathrm{N}}$)......…. (1)

ii. Simpson index (Simpson, 1949) (D = $\sum_{i=1}^{S} \frac{¿}{N} (\frac{¿-1}{N-1})$)).………….…..……...... (2)

iii. Pielou index of evenness (Pielou, 1966) (J $= \frac{H'}{\ln S}$) …………………….…... ….... (3)

iv. Margalef index of species richness (Margalef, 1958) (DMg =¿)).…..............… (4)

All these indices were calculated using the Paleontological Statistics software (PAST) Version 3.17 (Hammer, 1999-2017).

Beta diversity to highlight the composition of cucurbit infesting flies in each field was determined using Sorensen and Jaccard indices. According to formulae provided by Magurran (1988), the indices are equal to 1 when there is complete similarity between fields and approaches 0 when the fields have no species in common. Formulae used were;

i) Sorensen’s coefficient (Sc)=$\frac{a+b}{2c+a+b}$ ……………………...………...……… (1)

ii) Jaccard index $(jc) = \frac{b+c}{a+b+c}$ ………………………….…….….……………….... (2)

Whereas, Sc is a Sorensen's coefficient, *a* and b represent the number of unique species in the first and second field respectively, while c represented the number of shared species and Jc is Jaccard dissimilarity index.

2.4 Results

2.4.1 Fruit fly species abundance across ten cucurbit fields

In total, 21 673 fruit fly specimens were collected during the entire study period from ten established cucurbit fields. Specimens belonged to three genera (*Dacus, Zeugodacus and Bactrocera*) and 19 species. Of the total specimens collected, species from the genus *Zeugodacus* were the most dominant and accounted for 83.4% of the total specimens collected. While species from the genera Dacus and Bactrocera constituted the remaining 16.6% of the total specimens collected (Table 2.3).

2.4.2 Attractiveness of the different lures in relation to fruit fly's abundances

Of the 21673 fruit flies collected, *Zeugodacus cucurbitae* was the most abundant fly, followed *D. bivittatus* and *D. punctatifrons* (Table 2.3). Results also show that *D. durbanensis* Munro, *D. humeralis* (Bezzi) and *D. frontalis* Becker were more attracted to zingerone compared with biolure and CL. Results further show that traps baited with CL caught 84.7% of all specimen, while ZN and BL attracted 7.6 and 7.7% of fruit flies respectively. ZN had most catches of *D. durbanensis,* followed by *Z. cucurbitae* and *D. humeralis*. BL had higher catches of *Z. cucurbitae* followed by *D. vertebratus* Bezzi and *Dacus bivittatus* (Bigot) (Table 2.4).

2.4.3 Sampling effort

The sampling effort was sufficient to catch more than 78% of all fruit fly species infested cucurbit crops in each field (Table 2.5). The results from the sampling efforts indicated that only, few species remained un sampled because it is impossible to catch all species infesting crops in the field. In all fields, the asymptote number species were obtained and the total number of individuals were as indicated in. Moreover, the results also indicated that despite all fields had equal number of sampling days, the number of species caught varied among the fields. More catches were recorded at crop museum where more than 93% of the cucurbit infesting species were caught followed by horticulture unit (89%), Kifuru (86%), Mafiga (84%), Mazimbu (82%) and Mgola (81%). In the remaining fields the sampling efforts was sufficient to catch 78% of the cucurbit infesters at Morning side and Ruvuma and 79% at SUGECO and Mkumbulu (Table 2.5).

Table 2.3: Abundance of fruit flies in ten cucurbit fields within two agroecological zones of Morogoro, Tanzania

			Plateau zone					***Mountainous zone***				
Fruit fly Specie	CM	HT	SG	MF	MZ	MG	MK	MS	RV	KF	**Total**	**%**
B. dorsalis (Hendel)	1	1	7	2	13	72	138	2	99	4	339	1.6
Z. cucurbitae (Coquillet)	1298	675	1011	2133	969	4471	2408	742	4273	97	18077	83.4
D. bivittatus (Bigot)	44	10	22	47	39	87	83	127	104	20	583	2.7
D. punctatifrons Karsch	22	18	12	26	113	75	47	79	46	23	461	2.1
D. vertebratus Bezzi	39	2	78	6	6	9	3	1	3	0	147	0.7
D. ciliatus Loew	2	0	5	1	7	2	0	1	1	1	20	0.1
D. telfaireae (Bezzi)	0	3	0	1	0	13	20	387	8	214	646	3.0
D. durbanensis Munro	21	118	12	3	16	128	75	100	180	124	777	3.6
D. humeralis (Bezzi)	14	58	8	5	6	51	39	79	61	36	357	1.6
D. xanthopterus (Bezzi)	0	0	0	0	0	0	0	7	0	10	17	0.1
D. frontalis Becker	11	6	38	16	85	3	0	0	5	0	164	0.8
D. hyalobasis Bezzi	0	0	0	0	0	6	0	0	6	4	16	0.1
D. woodi Bezzi	0	0	0	0	0	26	0	0	4	0	30	0.1
D. ceropegiae (Munro)	0	0	0	0	0	1	0	0	0	0	1	0.0
D. annulatus Becker	0	0	1	0	0	0	0	0	2	0	3	0.0
D. chiwira Hancock	1	0	0	0	0	2	0	0	2	0	5	0.0
D. pulchralis White	0	0	0	0	0	1	0	6	0	5	12	0.1
D. nr brevistriga Walker	0	0	0	0	0	0	0	13	0	2	15	0.1
D. longistylus Wiedemann	1	0	0	0	0	0	0	0	0	0	1	0.0
D. sphaeristicus Speiser	0	0	0	0	0	1	0	0	0	0	1	0.0
Dacus spp.	0	0	0	0	1	0	0	0	0	0	1	0.0
Total	1454	891	1194	2240	1255	4948	2813	1544	4794	540	21673	100
Percentage	6.7	4.1	5.5	10.3	5.8	22.8	13.0	7.1	22.1	2.5	100	
Species Number	11	9	10	10	10	16	8	12	14	12	21	
Total per zone			7034					14639				
% per zone			32.5					67.5				
Species per zone			14					19				

Key: *CM; Crop Museum, HT; Horticulture, SG; SUGECO, MF; Mafiga, MZ; Mazimbu, MG; Mgola, MK; Mkumbulu, MS; Morning site, RV; Ruvuma, KF; Kifuru*

Table 2.4: Number of trapped specimens of cucurbit infesters

Fruit fly species	BioLure	Cue-Lure	Zingerone	Total	%
B. dorsalis (Hendel)	12	0	3	15	0.07
Zeugodacus cucurbitae (Coquillet)	275	16581	426	17282	84.83
Dacus bivittatus (Bigot)	21	516	14	551	2.70
D. punctatifrons Karsch	5	442	13	460	2.26
D. vertebratus Bezzi	7	50	4	61	0.30
D. ciliatus Loew	1	2	6	9	0.04
D. telfaireae (Bezzi)	16	600	19	635	3.12
D. durbanensis Munro	13	22	741	776	3.81
D. humeralis (Bezzi)	12	109	236	357	1.75
D. xanthopterus (Bezzi)	1	13	3	17	0.08
D. frontalis Becker	0	0	164	164	0.81
D. hyalobasis Bezzi	0	1	1	2	0.01
D. woodi Bezzi	0	4	2	6	0.03
D. ceropegiae (Munro)	0	1	0	1	0.00
D. annulatus Becker	0	2	0	2	0.01
D. chiwira Hancock	0	5	0	5	0.02
D. pulchralis White	0	11	1	12	0.06
D. nr brevistriga Walker	0	1	14	15	0.07
D. longistylus Wiedemann	0	1	0	1	0.00
D. sphaeristicus Speiser	1	0	0	1	0.00
Dacus spp.	0	0	1	1	0.00
Total	363	18361	1648	20373	100
Percentage %	1.8	90.1	8.1	100	

Table 2.5: Estimators of species richness based on abundance of fruit flies infesting cucurbit crops in ten fields in Morogoro, Tanzania

	Plateau zone					Mountainous zone				
Richness Estimator	Crop Museum	Horticulture Unit	SUGECO	Mafiga	Mazimbu	Mgola	Mkumbulu	Morning site	Ruvuma	Kifuru
Estimated sample	11.20	13.76	21.00	16.77	17.86	18.77	19.51	20.11	20.60	15.44
Mean	12.68	15.26	28.64	20.03	21.65	23.13	25.05	26.60	27.85	18.10
Chao 1 Mean	12.43	14.76	27.00	19.50	21.60	22.83	24.71	25.99	26.75	17.45
Jack 1 Mean	11.20	16.16	24.60	20.47	22.27	23.27	24.33	24.71	24.79	18.52
Mean of three ABE	12.10	15.39	26.75	20.00	21.84	23.08	24.70	25.77	26.46	18.02
Sampling effort %	**93**	**89**	**79**	**84**	**82**	**81**	**79**	**78**	**78**	**86**

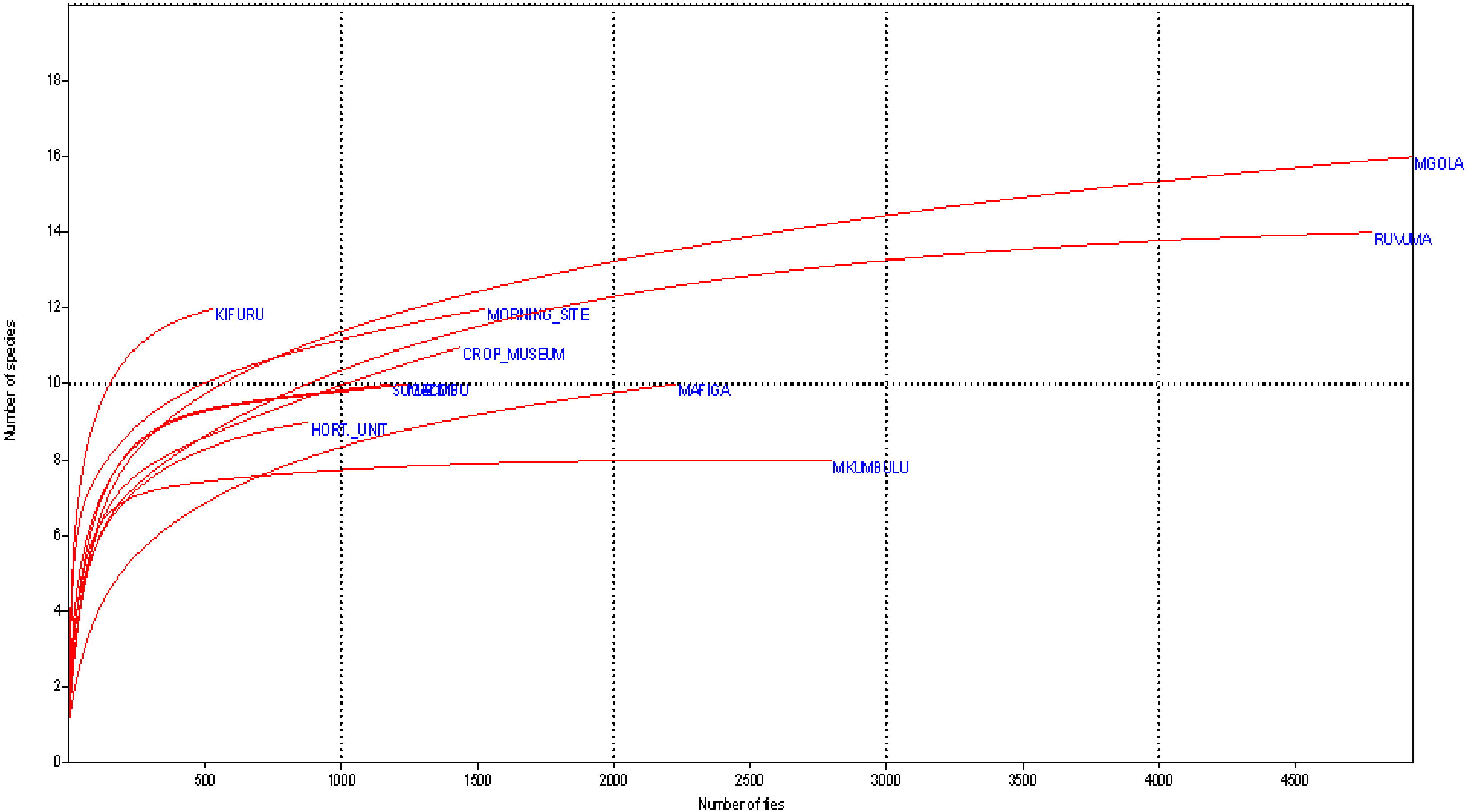

Figure 2.1: Species abundance accumulative curve of fruit flies

Table 2.6: Abundance of fruit flies captured in Bio lure in ten cucurbit fields within two agroecological zones of Morogoro, Tanzania

	Plateau zone					Mountainous zone					
Fruit fly Specie	CM	HT	SG	MF	MZ	MG	MK	MS	RV	KF	**Total**
B. dorsalis	1	0	1	2	3	1	1	0	3	0	12
Z. cucurbitae	12	15	16	20	13	28	20	29	101	21	275
D. bivittatus	1	0	1	1	2	0	2	8	5	1	21
D. punctatifrons	0	0	0	0	0	0	0	3	2	0	5
D. vertebratus	5	0	1	0	1	0	0	0	0	0	7
D. ciliatus	0	0	0	0	0	0	0	1	0	0	1
D. telfaireae	0	0	0	0	0	0	0	12	0	4	16
D. durbanensis	0	0	0	0	0	0	0	10	0	3	13
D. humeralis	0	0	0	0	0	0	0	9	0	3	12
D. xanthopterus	0	0	0	0	0	0	0	0	0	1	1
Total	19	15	19	23	19	29	23	72	111	33	363

Key: *CM; Crop Museum, HT; Horticulture, SG; SUGECO, MF; Mafiga, MZ; Mazimbu, MG; Mgola, MK; Mkumbulu, MS; Morning site, RV; Ruvuma, KF; Kifuru*

2.4.3 Alpha diversity of fruit flies

For the sake of brevity and clarity as well as avoiding the influence of different attractants on number of the flies collected only data from bio lure were used to compute both alpha and beta diversity indexes. As these indexes use both quantities and qualitative data to generate the indices values. A total of 363 specimens were collected from the ten established cucurbit fields (Table 2.6). Of these, 275 (75.6%) of specimens belonged to *Z. cucurbitae*, 76(21%) represented by species belonged to the genus *Dacus* and remaining 12 (3.3%) of the total specimens were *B. dorsalis*.

Morning side and Ruvuma fields showed the highest species diversity, with 7 and 6 number of species respectively, while Horticulture unit and Mgola had the lowest species diversity with 1 and 2 number of species respectively (Table 2.7). Only Z. *cucurbitae*, species occurred in all fields. The other remaining species were found in either among the ten cucurbit fields.

Based on rare species of fruit flies infesting cucurbit crops, the Shannon diversity index ranked Kifuru, Morning site, Mazimbu and Crop museum as the most diverse fields compared to Horticulture unit, Mgola, Ruvuma, Mkumbulu and SUGECO as well as Mafiga which had relatively small Shannon diversity values (Table 2.7). Likewise, the Simpson index which account for dominant species within fields ranked Kifuru, Morning site and Crop museum as the most diverse fields compared to the other remaining seven fields which had relatively small values of Simpson index (Table 2.7).

According to the results of Margalef index, Crop museum, Kifuru, SUGECO, Mazimbu and Morning site were the most species rich fields while Horticulture unit and Mgola were the least species rich fields. The other remaining fields had moderate species richness values throughout the study period. The evenness values showed considerable differences in even distribution of fruit flies among the fields. The highest evenness value was recorded at Horticulture unit (1.00), Morning site (0.73), Crop museum (0.647) and Mazimbu (0.642) while the lowest value was obtained at Ruvuma (0.371) and SUGECO (0.46). The remaining fields had moderate evenness values ranging from 0.534 at Mafiga and Mkumbulu to 0.549 at Kifuru and 0.581 Mgola (Table 2.7).

Table 2.7: Diversity and richness index of fruit flies infesting cucurbit crops in ten fields in Morogoro, Tanzania

	Plateau zone					Mountainous zone				
Index	Crop museum	Horticulture Unit	SUGECO	Mafiga	Mazimbu	Mgola	Mkumbulu	Morning site	Ruvuma	Kifuru
Fly species	4	1	4	3	4	2	3	7	4	6
Individuals	19	15	19	23	19	29	23	72	111	33
Simpson_1-D	0.526	0.000	0.283	0.234	0.493	0.067	0.234	0.761	0.169	0.562
Shannon_H	0.952	0.000	0.610	0.470	0.943	0.150	0.470	1.635	0.396	1.191
Evenness	0.647	1.000	0.460	0.534	0.642	0.581	0.534	0.733	0.371	0.549
Margalef	1.019	0.000	1.019	0.638	1.019	0.297	0.638	1.403	0.637	1.430

2.4.4 Beta diversity of fruit flies

In this study, beta diversity indices were used as a measure on how different or similar fields are in terms of the variety of species found in them (Mwatawala *et al.*, 2006). In order to achieve this, the species composition of the different fields was compared using Jaccard and Sorensen indices (Table 2.8 and 2.9). Results showed that the species composition among fields within the plateau and mountainous zones differed considerably. The Sorensen indices values between fields ranged from 0.22 to 1 (Table 2.8). A complete similarity was recorded when Mkumbulu field from the mountainous zone compared to Mazimbu field from the plateau zone (Sc=1). Likewise, high similarities in species composition were recorded when Mazimbu field from plateau zone compared to Mgola and Ruvuma which all from mountainous zone as well as when Mkumbulu compared to Crop museum and Mafiga (Sc=0.8). Moreover, the lowest similarity recorded when Morning site and Kifuru compared to all fields from the plateau zone (Sc <0.5) (Table 2.8).

In the plateau zone, a complete similarity in species composition between fields was recorded when Mafiga and SUGECO compared to Crop museum. Similarly, high similarity was also recorded between Mazimbu and Crop museum as well as Mafiga and SUGECO compared to Mazimbu.

On other hand high dissimilarities in species composition among fields was recorded when Horticulture unit compared to Mafiga Mazimbu, and SUGECO as well as compared to Crop museum (Table 2.8). Levels of species similarity between the fields in the plateau zone were all >0.5 and dissimilarities were all <0.33. While in the mountainous zone, the level of similarities were all > 0.4. The highest similarity value was observed when Mgola field compared with Mkumbulu and Ruvuma. Likewise, highest similarity value was recorded between Ruvuma, Mkumbulu, Morning side and Kifuru as well as Morning side. On other hand, the lowest similarity value was recorded Kifuru was compared with Mgola, Mkumbulu and Ruvuma fields as well as when Morning side was compared to Mkumbulu field.

On the contrary, the Jaccard indices seemed to be less sensitive to similarity detection. This is because its index values were low compared to Sorensen indices. The Jaccard indices values between fields ranged from 0.13 to 1.0 (Table 2.9). However, complete similarity value was observed when Crop museum field was compared with the Mafiga and SUGECO as well as when SUGECO compared to Mafiga. Similarly, high similarity value was recorded when Mazimbu was compared to Crop Museum, Mafiga and SUGECO. On other hand, the lowest similarity index was recorded when Horticulture unit field compared to SUGECO, Mafiga and Crop museum. All these fields are from plateau zone.

In the mountainous zone the highest similarity value recorded when Mkumbulu was compared with Mgola and Ruvuma field. Similarly, highest similarity value was obtained when Kifuru field compared to Morning side and when Ruvuma compared to Mgola field. On other hand, lowest similarity indices were recorded when Morning side field was compared with Mgola, Mkumbulu and Ruvuma. Likewise, lowest similarity value was obtained when Kifuru was compared with Mkumbulu and Ruvuma fields. All these fields are from mountainous zone (Table 2.9).

Table 2.8: Sorensen index of fruit flies studied at different locations in two agroecological zones of Morogoro

Zone	Field	CM	HT	MF	MZ	SG	MG	MK	MS	RV
Plateau	Crop museum									
		0.4								
	Hort. Unit	0								
		1.0	0.4							
	Mafiga	0	0							
		0.8	0.5	0.8						
	Mazimbu	6	0	6						
		1.0	0.4	1.0	0.8					
	SUGECO	0	0	0	6					
		0.6	0.6	0.6	0.8	0.6				
Mountainous	Mgola	7	7	7	0	7				

Mkumbulu	0.86	0.50	0.86	1.00	0.86	0.80			
Morning site	0.36	0.25	0.36	0.40	0.36	0.22	0.40		
Ruvuma	0.75	0.40	0.75	0.86	0.75	0.67	0.86	0.55	
Kifuru	0.40	0.29	0.40	0.44	0.40	0.25	0.44	0.77	0.40

Key: *CM; Crop Museum, HT; Horticulture, MF; Mafiga, MZ; Mazimbu, SG; SUGECO, MG; Mgola, MK; Mkumbulu, MS; Morning site, RV; Ruvuma*

Table 2.9: Jaccard indices of fruit flies studied at different locations in two agroecological zones of Morogoro.

Zone	Field	CM	HT	MF	MZ	SG	MG	MK	MS	RV
Plateau	Crop museum									
	Hort. Unit	0.25								
	Mafiga	1.00	0.25							
	Mazimbu	0.75	0.33	0.75						
	SUGECO	1.00	0.25	1.00	0.75					
Mountainous	Mgola	0.50	0.50	0.50	0.67	0.50				
	Mkumbulu	0.75	0.33	0.75	1.00	0.75	0.67			
	Morning site	0.22	0.14	0.22	0.25	0.22	0.13	0.25		
	Ruvuma	0.60	0.25	0.60	0.75	0.60	0.50	0.75	0.38	
	Kifuru	0.25	0.17	0.25	0.29	0.25	0.14	0.29	0.63	0.25

Key: *CM; Crop Museum, HT; Horticulture, MF; Mafiga, MZ; Mazimbu, SG; SUGECO, MG; Mgola, MK; Mkumbulu, MS; Morning site, RV; Ruvuma*

2.5 Discussion

The alpha diversity indexes pointed out differences in species diversity and richness between the ten cucurbit fields across the plateau and mountainous zone of the Morogoro region. This difference in fruit fly diversity and richness is not surprising because the two agroecological zones differ in climatic conditions, availability of host crops, surrounding natural vegetation and forest reservoirs as well as agricultural activities. Similar results were reported by Gnanvossou *et al.* (2017) and Mwatawala *et al.* (2006) who related the abundance of fruit flies with weather parameters, host crops and agroecological zones. The observed diversity of fruit flies collected across the two agroecological zones underlines the prevalence of *Z. cucurbitae*, *Bactrocera dorsalis* and *D. bivittatus* in the two sites.

The dominant representatives of the genera Zeugodacus and Dacus that were collected in all fields are all cucurbit feeders. Similar results were also reported by Dhillon *et al.* (2005) Mwatawala *et al.* (2006), who recorded the presence of cucurbit infesters in three agroecological zones of the Morogoro region. The other species from the genus Dacus were also found but in low numbers, often represented by very few specimens per field as in case of *D. ceropegiae, D. annulatus, D. chiwira, D. longistylus, D. sphaericticus* and *Dacus spp.* These species are of no economic importance, and could be associated with cucurbit crops due to either their polyphoguos or monophagous nature. A study by Hafsi *et al.* (2016) indicated that insect species differ in their degree of specialization on host plants, and range from strictly monophagous species host plant to extremely polyphagous species in many families.

In the plateau zone, the Crop museum was the most diverse field with regard to number of fruit fly species collected and the Horticulture Unit was the less diverse field in fruit fly fauna. High number of fruit fly species at Crop museum could be due to the presence of host crops which provide reservoirs for cucurbit infesters to multiply throughout the year. The low proportion of the observed Horticulture fruit fly fauna could be due low availability of host crops and continuous application of insecticides and trapping in the surroundings. Likewise, the Mgola field was the most diverse field and Mkumbulu was the least diverse field in the mountainous zone. Similar results indicating differences in diversity between sites was also reported by Ganie *et al.* (2013) who studied the diversity of cucurbit infesters from cucumber, bottle gourd, ridge gourd, and bitter gourd across the Budgam and Srinagar districts in India.

Proximity of natural habitats and partly presence of forest along the Uluguru Mountain to the fields in mountainous zone could be played as a source of higher diversity in the mountainous sites compared to the plateau sites which are largely in a landscape that is predominated by conventional agriculture. Fields from mountainous zone were notably abundant and most diverse in fruit flies compared to the plateau zone. This difference may be due to variation in agroecological system as well as cropping pattern of the experimental location. Species diversity and species richness were highest in mountainous zone and lowest in plateau zone, as the highest number of species were found in mountainous zone and the lowest were found in plateau zone.

On other hand, all fields were highly similar in term of species composition. This could be due to the fact that the distribution of most of these cucurbits infesting fruit flies is expanded to all agroecological zones of the Morogoro region. Mwatawala *et al.* (2010)

and Deguine *et al.* (2012) studies stressed out that cucurbit infesting flies could be found from very minimum altitude of about 100 m above sea levels to 1750 m and above.

2.6 Conclusion

The study established the biodiversity of cucurbit infesting flies across the plateau and mountainous zone. It therefore highlights the need for considering agroecological zones, availability of host crops and surrounding vegetation on designing a sustainable control strategy for fruit flies. Results of this study provides information useful for the development of a comprehensive and sustainable management tool of *Z. cucurbitae* and other cucurbit flies in Morogoro.

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CHAPTER THREE

Seasonal abundance of fruit flies (Diptera: Tephritidae) in cucurbitaceous production systems in Morogoro Region, Eastern Central Tanzania

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To be submitted to: Journal of Insect Science (OXFORD)

3.1 Abstract

Many of these cucurbit infesters have been less studied in Africa compared to developed countries, and compared to fruit infesting tephritids. The abundance and distribution of these cucurbit infesters in Tanzania have largely remained unknown. Therefore, a study was carried out to assess the spatial and temporal abundance of *Dacus*, *Bactrocera* and *Zeugodacus* species infesting cucurbit crops across the different agroecological zones: plateau zone and mountainous zone, of the Morogoro region over three growing seasons from March to November 2020. Three cucurbit crop species; cucumber (*Cucumis sativus* L.), watermelon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai), and Squash (*Cucurbita moscharta* D.) were planted in each of five plots established in each of the two agroecological zones. Weekly trappings of cucurbit infesters were carried out with Cue-Lure, BioLure and Zingerone. A total of 21 673 flies were collected. On overall, *Zeugodacus cucurbitae* was the most abundant species, followed by *Dacus bivittatus* and *D. punctatifrons*. Cropping period and fruit fly species showed significant effects on abundance of three dominant fruit fly species ($P<0.05$). Similarly, the interaction between fruit fly species and cropping period as well as agroecological zone and cropping period had significant effects on abundance of the two dominant fruit fly species ($P<0.05$). *Zeugodacus cucurbitae* was the dominant in both altitudes throughout the cropping seasons. The results imply that numbers of trapped flies will vary with season and agroecological zones.

Key words: Seasonal abundance, fruit flies, cucurbit crops

3.2 Introduction

Fruit flies (Diptera: Tephritidae) are major pests of horticulture. Major pest genera are of limited geographic distribution (White and Elson Harris, 1994). Some species have been introduced into exotic places. The genera *Ceratitis* and some *Dacus* species are native to Africa, while some *Bactrocera* and *Zeugodacus* have invaded Africa at different times. Major species in the Afrotropical region include *Zeugodacus cucurbitae* (Coquillett), *Dacus ciliatus* Loew, *D. vertebratus* Bezzi, *D. bivittatus* (Bigot) and *D. punctatifrons* (Bigot). Unfortunately, apart from *Z. cucurbitae,* these species have been less studied compared with native *Ceratitis* species and the invasive *Bactrocera dorsalis* (Hendel) (Mwatawala *et al*., 2006).

Knowledge on spatial and temporal abundance and their distribution is an important prerequisite for formulating sound management programs against fruit flies. Monitoring data in Africa are mostly limited to *Z. cucurbitae* (Vayssieres *et al.*, 2007; Mwatawala *et al*., 2010; Ganie *et al*., 2013). Monitoring of cucurbit infesters is mostly done using parapheromones and food baits. Cue lure (4-(p-acetoxyphenyl)-2-butanone) is a potent attractant for cucurbit infesters that has been widely used in many parts of Africa (Mwatawala *et al.,* 2006; Manrakhan, 2016). However, some of economically important species *D. ciliatus* and *D. vertebratus* do not respond to this parapheromone. *Dacus vertebratus* is attracted to a more specific vertlure. A new promising attractant for some of the Dacine is zingerone (4-hydroxy, 3-methoxyphenyl-2-butanone). According to Manrakhan (2016) zingerone is attractive to some Dacus species including *Dacus frontalis* Becker.

Previous studies in Tanzania did not include zingerone (Mwatawala *et al.,* 2006). Further evaluation of this novel attractant is warranted in Africa in order to determine the response of African Dacine to this lure (Manrakhan, 2016).

Clearly there is a need for both sound data on the current occurrence of fruit flies in Africa through monitoring programmes, as well as rapid detection and surveying programmes to quickly identify new intrusions (De Meyer and Ekesi, 2016). Testing new emerging attractants in different agroecological zones is also necessary. Seasonal abundance of fruit flies like other insects is modulated by both biotic and abiotic factors as well as human intervention such as application of insecticides. Key factors include availability and abundance of hosts, crop phenology, competition, natural enemies, life history strategies adopted by a pest, and weather factors like temperature and humidity. Cucurbitaceous vegetables form an important part of human diets. They are a source of livelihood to many smallholder farmers across the world. Commercially important crops include watermelon, cucumber, pumpkin and squash, mostly sold in local urban markets. Production of these vegetable crops is however hampered by various factors, including insect pests, notably fruit flies.

There is always a correlation between abundance of pests and damage inflicted on hosts. It is expected that abundance of cucurbit infesters would vary over time among, species, altitudes, seasons and attractants. Effective management of cucurbit infesters is therefore crucial if optimum production is to be realized. The present studies aimed at determining spatial and temporal distribution of major cucurbit infesters in Morogoro, Region, and Eastern Central Tanzania. Data from this study will be used in formulating an agroecological management system against cucurbit infesters.

3.3 Materials and Methods

3.3.1 Study site

Studies on the seasonal abundance of cucurbit infesting flies were conducted from March to November 2020 in Morogoro Region in eastern-central Tanzania. Morogoro Region is located in the transition zone between the bimodal and unimodal rainfall belts at S5°58’-S10°0’South and E35°25’- E38°30’ East (URT, 2002). Study sites were selected between October and November 2019 within plateau and mountainous zones of Morogoro (Table 3.1). River valley and basins zone was excluded because of dominance of flooded paddy fields.

Table 3.1: Agroecological zones of Morogoro Region

Zone	Characteristics
Mountainous zone	Altitude: > 600 meters asl; Average rainfall: 800 mm – 2500 mm p.a
Plateau	Altitude: 300-600 meters asl; Average rainfall: 700 mm – 1200 mm p.a
River valleys and basins	Altitude: < 300 meters asl; Average rainfall: 900 mm – 1400 mm p.a

Source: URT 2002.

Ten experimental plots were established in ten different localities within two agroecological zones namely, the plateau and mountainous zones of Morogoro (Table 3.2). In each agroecological zone five experimental plots located at least 1 km apart from each other were established. Selected hosts were cucumber (*Cucumis sativus* L.), variety “Ashley”, and watermelon (*Citrullus lanatus* [Thunb.] Matsum. & Nakai), variety “Sugar baby” and squash (*Cucurbita maxima* L.) variety “Waltham”. Cucumber, watermelon and squash were each planted on a 0.25-acre (1012 m^2) plot at a spacing of 50 cm x 60 cm, 1 m × 1.5 m and 1 m × 1.5 m respectively.

Table 3.2: Experimental field locations in two agroecological zones of Morogoro

Location of field plots in two different Agro ecological zones			
Location	**Coordinates**	**Altitude**	
SUA Horticulture Unit (HT)	S06˚50'41.4" E37˚39'43.3"	524 m	**Plateau zone**
SUA Crop Museum (CM)	S06˚51'00.53" E37˚39'17.90"	528 m	
SUGECO (SG)	S06˚50'22" E37˚38'42.2"	511 m	
SUA Mazimbu (MZ)	S06˚47'26.208" E37˚38'7.926"	486 m	
SUA Mafiga (MF)	S06˚50'22.764" E37˚37'53.46"	503 m	
Morning Site (MS)	S06˚53'17.9" E37˚40'14.93"	1274 m	**Mountainous zone**
Mkumbulu (MK)	S06˚52'24.2" E37˚40'21.5"	1105 m	
Ruvuma (RV)	S06˚52'34.6" E37˚40'3.7"	995 m	
Kifuru (KF)	S06˚53'32.1" E37˚40'9.5"	1418 m	
Mgola (MG)	S06˚51'41.4" E37˚40'4.3"	1084 m	

3.3.2 Baits and trapping

Trapping was conducted from March to November 2020 in ten established cucurbit fields focusing on cucurbit infesting flies. Tephri traps were baited with one of three different baits Cue-lure (CL), Zingerone (ZN) and BioLure (BL, containing putrescine, trimethylamine and ammonium acetate) to attract members of the genera *Dacus* and *Zeugodacus*. CL and ZN are male specific while BL attracts flies of both sexes. Zingerone was available in crystalline form, which was melted at 40°C in a glass beaker using heated bath method (Manrakhan *et al*., 2017; Inskeep *et al*., 2018). Once liquid, ZN was applied with a graduated pipette to individual 1 x 3 cm cotton dental wicks (Royer, 2015). CL was available as a plug while BL was supplied in a sachet. Traps were set following guidelines by IAEA (2003). Three traps each baited with one attractant were placed on tree branches or held on wooden poles at a height of 1.5 m above the ground at least 30 m apart from each other. A strip of an insecticide dichlorvos (DDVP) placed at the bottom of each trap to kill trapped insects. Sticky glue (Tanglefoot) was applied at the base of branches or poles where to prevent ants from accessing traps. Traps were inspected once a week, and catches were placed in vials marked with unique numbers corresponding to a data sheet with details on date, location and lure. In order to minimize location bias traps were rotated clockwise after each inspection. Attractants and insecticide strips were replaced every four weeks. Collected specimen were transported to the entomology laboratory at SUA and preserved in 70% ethanol prior to sorting and identification.

3.3.3 Data collection and identification

Data were entered as number of fruit flies per trap per day (FTD) at different cucurbit phenological stages. Fruit fly morphological identification to species level was done with the aid of binocular stereomicroscope using keys and characters presented by White and Elson-Harris (1994), White (2006), Ekesi and Billah (2007) and electronic keys by Virgilio *et al*. (2014). For further identification and confirmation some specimens were sent to the Royal Museum for Central Africa (RMCA). Weather data were collected from the Tanzania Meteorological Agency (TMA) at SUA.

3.3.4 Statistical analysis

Analysis of Variance (ANOVA) was used to determine the effects of cropping season, agroecological zone, fruit fly species and week after transplanting on abundance fruit flies. Host was not included as a factor because a single set of attractants was placed in a plot of all three crops. Only data from BL traps, that were active from late June to early November, were used in ANOVA, for two most abundant species that occurred at both zones. Log linear regression with Poisson distribution as used by Vayssieres *et al.* (2019) was adopted to determine association between weather and hosts phenology with abundance of flies. Only data collected from the Plateau zone sites, which were within the 5 – 10 kms range from the weather station, were used for regression analysis. Three most abundant species based on total catches, were included in analyses. Data were analysed using statistical package JMP Pro version 14.3 (SAS Institute Inc., Cary, North Carolina).

3.3 Results

3.3.1 Seasonal abundance of cucurbit infesters

A total of 21 673 flies were trapped as presented in Table 3.3. *Zeugodacus cucurbitae* was the most abundant fly, followed *D. bivittatus* and *D. punctatifrons* (Table 3.3). Results also show that *D. durbanensis* Munro, *D. humeralis* (Bezzi) and *D. frontalis* Becker were more attracted to zingerone compared with biolure and CL. Results further show that traps baited with caught CL 84.7% of all specimen, while ZN and BL attracted 7.6 and 7.7% of insects respectively. ZN had most catches of *D. durbanensis,* followed by *Z. cucurbitae* and *D. humeralis*. BL had higher catches of *Z. cucurbitae* followed by *D. vertebratus* Bezzi and *Dacus bivittatus* (Bigot).

Table 3.3: Number of trapped specimens of cucurbit infesters

Fruit fly species	BioLure	Cue-Lure	Zingerone	Total	%
B. dorsalis (Hendel)	12	0	3	15	0.07
Z. cucurbitae (Coquillet)	275	16581	426	17282	84.83
Dacus bivittatus (Bigot)	21	516	14	551	2.70
D. punctatifrons Karsch	5	442	13	460	2.26
D. vertebratus Bezzi	7	50	4	61	0.30
D. ciliatus Loew	1	2	6	9	0.04
D. telfaireae (Bezzi)	16	600	19	635	3.12
D. durbanensis Munro	13	22	741	776	3.81
D. humeralis (Bezzi)	12	109	236	357	1.75
D. xanthopterus (Bezzi)	1	13	3	17	0.08
D. frontalis Becker	0	0	164	164	0.81
D. hyalobasis Bezzi	0	1	1	2	0.01
D. woodi Bezzi	0	4	2	6	0.03
D. ceropegiae (Munro)	0	1	0	1	0.00
D. annulatus Becker	0	2	0	2	0.01
D. chiwira Hancock	0	5	0	5	0.02
D. pulchralis White	0	11	1	12	0.06
D. nr brevistriga Walker	0	1	14	15	0.07
D. longistylus Wiedemann	0	1	0	1	0.00
D. sphaeristicus Speiser	1	0	0	1	0.00
Dacus spp.	0	0	1	1	0.00
Total	**363**	**18361**	**1648**	**21673**	**100**
Percentage %	**1.8**	**90.1**	**8.1**	**100**	

3.3.2 Seasonality of major cucurbit infesters

Results further show significant effects of agroecological zone, and fruit fly species and the interactions between on abundance of three dominant fruit fly species ($P<0.05$) (Table 3.4). The effects of interaction between agroecological zone × fruit fly species as well as cropping period × fruit fly species (Table 3.4). The results imply that numbers of trapped flies will vary significantly with cropping period and agroecological zone.

Table 3.4: ANOVA results on effect of season, altitude, fly species and week after transplanting on the abundance of fruit flies

Source	df	SS	F-Ratio	Prob > F
Cropping Season (S)	1	0.0058	2.7218	0.1002
Agroecological zone (AZ)	1	0.0405	18.7549	<.0001*
Trapping Week (W)	7	0.0099	0.6588	0.7068
Fly species (F)	1	0.1645	76.2150	<.0001*
S × AZ	1	0.0009	0.0425	0.8368
S × W	7	0.0045	0.3024	0.9524
S × F	1	0.0125	5.7885	0.0168*
AZ × W	7	0.0061	0.4044	0.8992
AZ × F	1	0.0392	18.1642	<.0001*
W × F	7	0.0106	0.7068	0.6663
S × AZ × W	7	0.0050	0.3321	0.9389
S × AZ × F	7	0.0019	0.1289	0.9962
S × W × F	1	0.0002	0.0756	0.7836
AZ × W × F	7	0.0009	0.0641	0.9996
S × AZ × W × F	7	0.0023	0.1512	0.9937

** indicates significance*

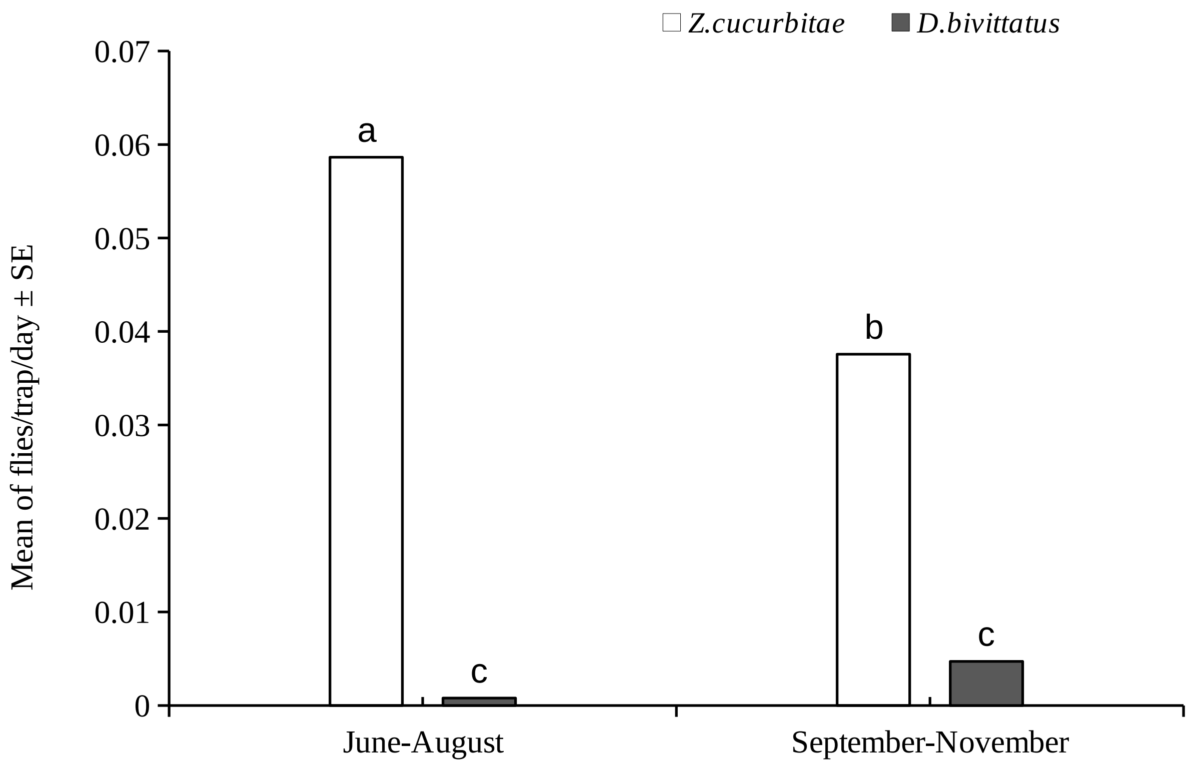

Figure 3.1 Mean number of fruit flies caught by Bio lure from June to November in the Morogoro region

Post hoc turkey showed significant catch of *Z. cucurbitae* among the cropping season ($P>0.05$). High catches were obtained between June to August and lower catches were recorded from September to November. In contrary to *Z. cucurbitae*, *D. bivittatus* showed no significant difference in abundance between the two cropping seasons. (Fig.3.1). *Posthoc* Tukey test showed significantly higher numbers of *Z. cucurbitae* during

June – August period than the September – November period. On the contrary, catches of *D. bivittatus* were significantly higher during the September – November period than the June – August period (Figure 3.1).

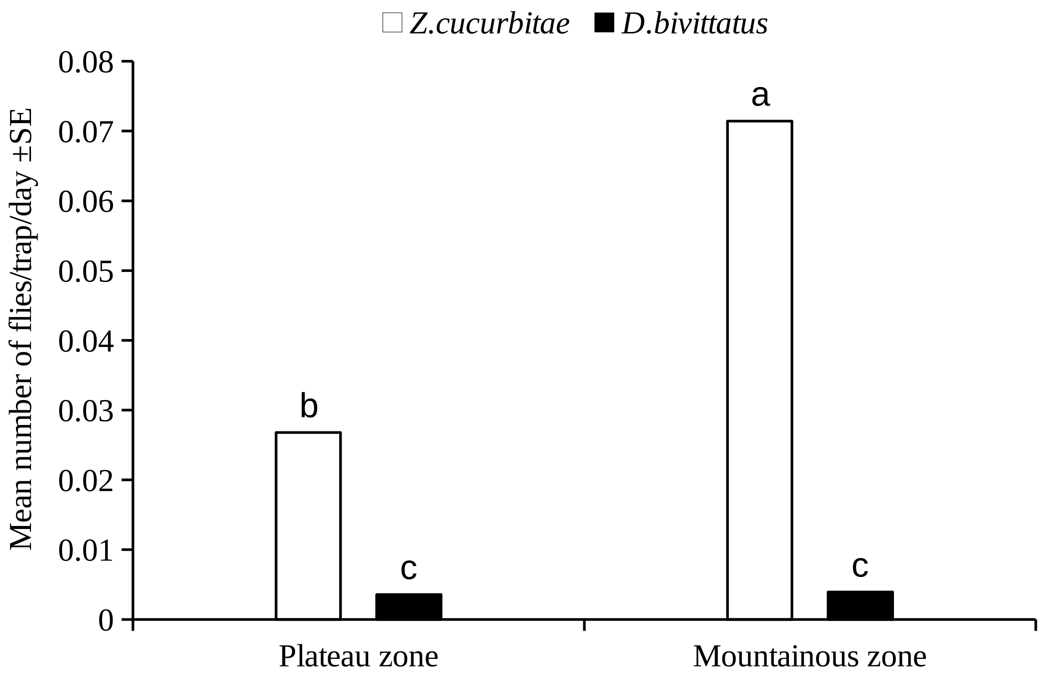

Figure 3.2: Mean number of fruit flies caught by Bio lure from the two agroecological zone of the Morogoro region

Post hoc turkey showed significant catch of *Z. cucurbitae* between the agroecological zones (P>0.05). High catches were obtained in mountainous zone and lower catches were recorded from plateau zone. In contrary to *Z. cucurbitae, D. bivittatus* showed no significant difference in abundance between the plateau and mountainous zones (Fig. 3.2).

3.3.3 Seasonal fluctuation and abundance of dominant fruit fly species associated with cucurbit crops

Figures 3.3 and 3.4 shows seasonal abundance of the three main species. The abundance of *Z. cucurbitae* was higher than *D. bivittatus* and *D. vertebratus* at both altitudes. At the plateau zone, the abundance of *Z. cucurbitae* was high during the late June to mid-July period, and gradually declined towards the November. The abundance at the mountainous zone did not vary much with time except for a drop in early September. The abundance of *Z. cucurbitae* was generally higher at the plateau than mountainous zone. *Dacus bivittatus* and *D. bivittatus* had generally low populations throughout (Figures 3.3 to 3.4).

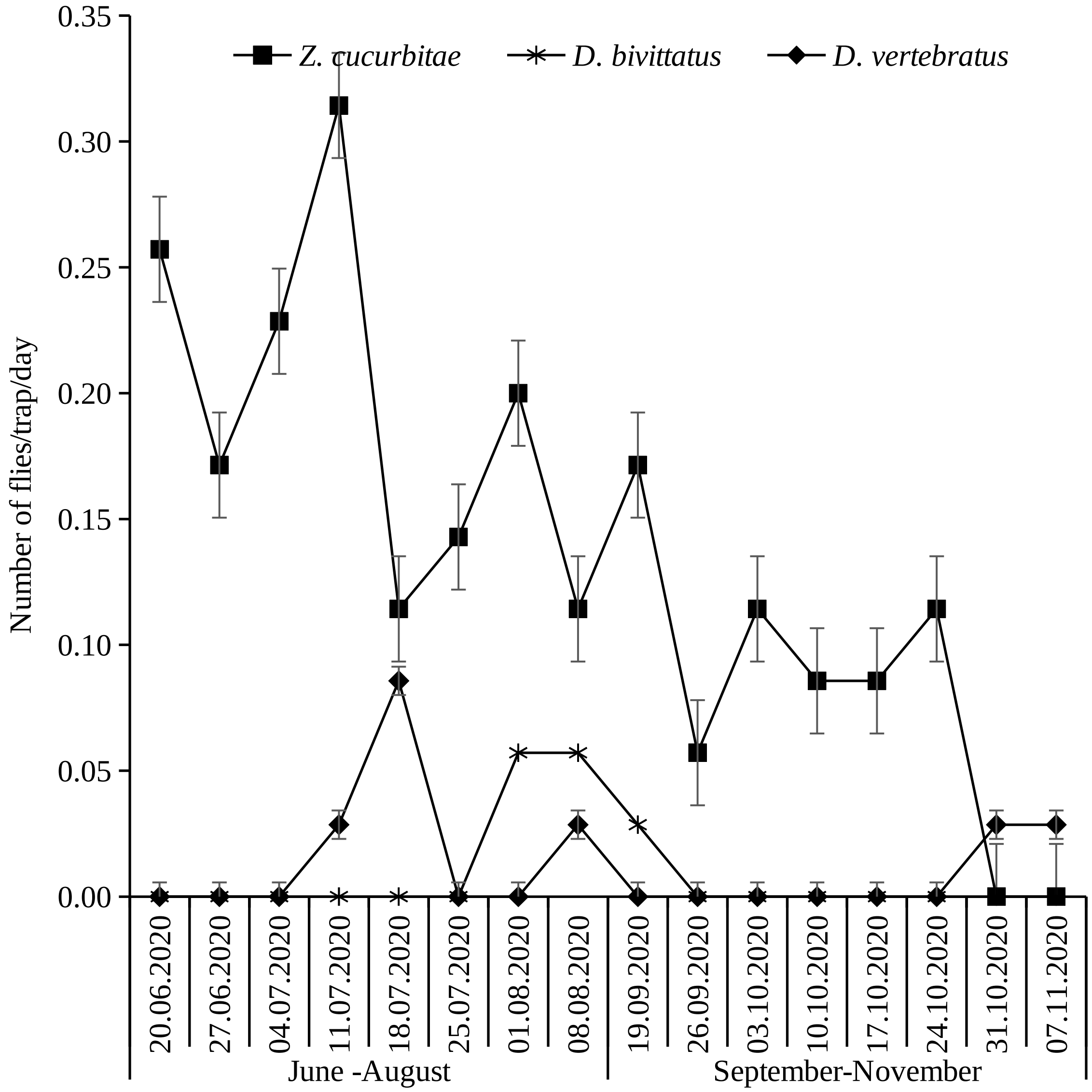

Figure 3.3: Seasonal abundance of fruit flies in plateau zone caught by Bio lure from June to November, 2020.

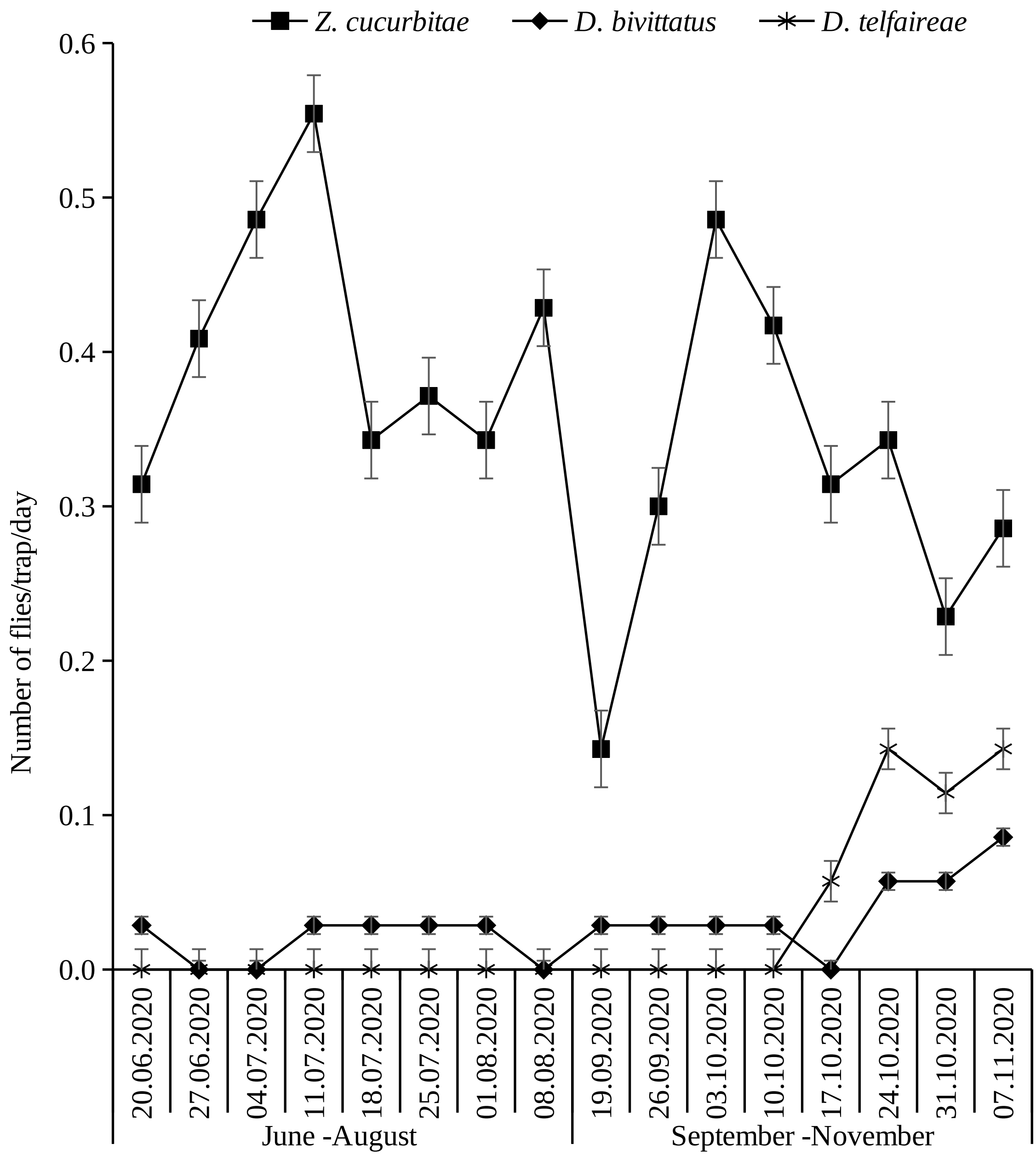

Figure 3.4: Seasonal abundance of fruit flies in mountainous zone caught by Bio lure from June to November, 2020.

3.3.4 Lure effectiveness

Source	Nparm	DF	SS	F Ratio	Prob > F
Agroecological zone (AZ)	1	1	31.32147	4.4473	0.0367*
Cropping season (S)	1	1	3.93934	0.5593	0.4557
Lure (L)	2	2	423.11846	30.0387	<.0001*
Fly species (F)	2	2	442.87163	31.4411	<.0001*
AZ × S	1	1	38.89836	5.5231	0.0201*
AZ × L	2	2	9.55304	0.6782	0.5091
AZ × F	2	2	0.61989	0.0440	0.9570
S × L	2	2	3.01689	0.2142	0.8075
S × F	2	2	6.13541	0.4356	0.6477
L × F	4	4	743.66005	26.3976	<.0001*
AZ × S × L	2	2	33.37639	2.3695	0.0972
AZ × S × F	2	2	22.45089	1.5939	0.2067
AZ × L × F	4	4	28.05915	0.9960	0.4118
S × L × F	4	4	16.98598	0.6029	0.6611
AZ × S × L × F	4	4	61.35290	2.1778	0.0744

** indicates significance*

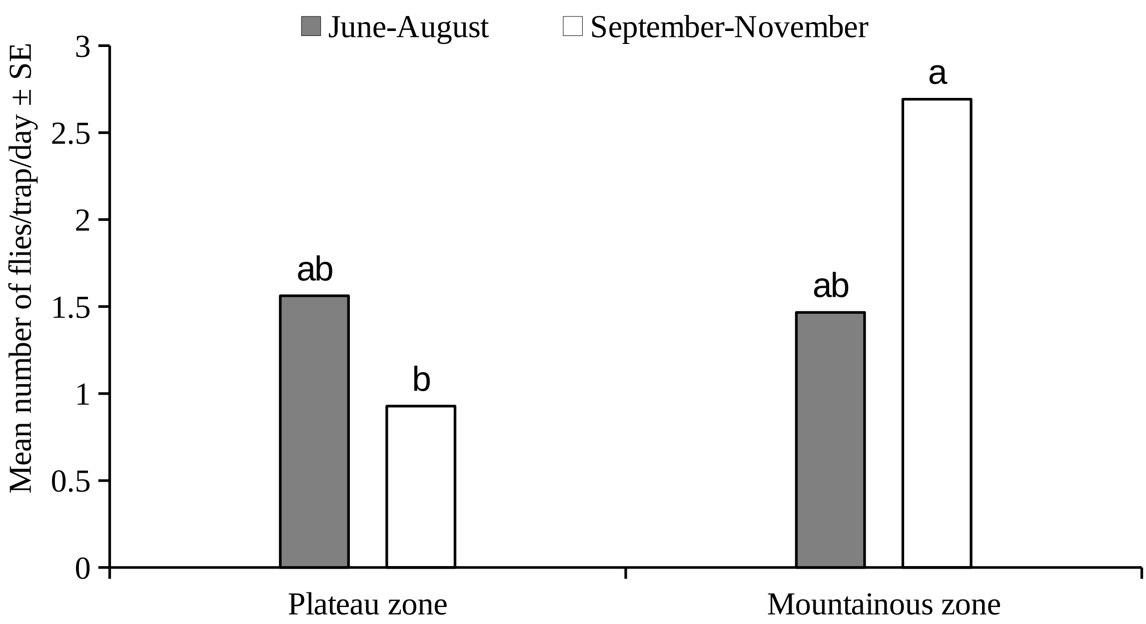

Figure 3.5 Mean number of fruit flies caught from the two agroecological zone by Bio lure from the month June to November 2020.

Table 3.5: Posthoc Tukey test results for lure and species interaction

Species	Mean
D. durbanensis × BioLure	0.03b
D. telfaireae × BioLure	0.04b
Z. cucurbitae × BioLure	0.68b
D. durbanensis × Cue-Lure	0.05b
D. telfaireae × Cue-Lure	1.39b
Z. cucurbitae × Cue-Lure	9.94a
D. durbanensis × Zingerone	1.76b
D. telfaireae × Zingerone	0.05b
Z. cucurbitae × Zingerone	1.01b

Posthoc Tukey test on attractiveness between lures to fruit fly species showed that CL attracted significantly higher number of *Z. cucurbitae* than all other lures. The effects of all lures on the remaining species were not significantly different (Table 3.5).

3.3.5 Association between weather, phenology and fly abundance

Results showed significant association between relative humidity, rainfall, minimum temperature, and phenological stages (except flowering) with abundance of *Z. cucurbitae* ($P<0.05$) (Table 3.6). Abundance is likely to be higher during flowering stage (Exp [0.03] = 1.03) and fruit setting (Exp [0.89] = 2.45) compared with vegetative stage. Abundance is also expected to increase with maximum temperature (Exp [0.06] = 1.06), minimum temperature (Exp [0.203] = 1.23) and relative humidity (Exp [0.05] = 1.05). However, increase in rainfall is likely to reduce abundance of *Z. cucurbitae* (Exp [-0.003] = 0.997).

Table 3.6: Estimates for Poisson regression of infestation rate of *Z. cucurbitae* as affected by host phenology and weather

Term	Estimate	SE	Chi square	P-Value
Intercept	-6.889871	1.3465413	25.833854	<.0001*
Flowering	0.0263389	0.0335329	0.6168903	0.4322
Fruiting	0.8971893	0.0322838	877.70502	0.0001*
After fruiting	-0.681112	0.0586273	163.9318	0.0001*
Maximum temperature	0.061477	0.0321679	3.6372292	0.0565
Minimum temperature	0.2033968	0.0253675	63.553945	0.0001*
Rainfall	-0.002735	0.000396	47.407816	0.0001*
Relative humidity	0.04903	0.0111988	18.829712	0.0001*

** indicates significance, vegetative stage is the reference*

Results also showed significant association between relative humidity, rainfall, minimum temperature, and phenological stages with abundance of *D. bivittatus* (Table 3.7). Higher abundance of *D. bivittatus* is expected during fruit setting (Exp [1.073] = 2.93) but lower during (Exp [-.0.68] = 0.51) compared with vegetative stage. Abundance is also expected to decrease with increase in rainfall (Exp [-0.003] = 0.997).

Table 3.7: Estimates for Poisson regression of infestation rate of *D. bivittatus* as affected by host phenology and weather

Term	Estimate	SE	Chi square	P-Value
Intercept	-8.750718	7.9693368	1.1957976	0.2742
Flowering	-0.445971	0.2386785	3.7157931	0.0539
Fruiting	0.8676112	0.1977896	21.153614	<.0001*
After fruiting	-1.063456	0.3425985	12.818969	0.0003*
Maximum temperature	-0.134484	0.2084606	0.4215294	0.5162
Minimum temperature	0.2881457	0.1337057	4.5023955	0.0338*
Rainfall	-0.007574	0.0023372	10.284731	0.0013*
Relative humidity	0.0810741	0.0574645	1.999457	0.1574

** indicates significance, vegetative stage is the reference*

The associations between relative humidity, rainfall, minimum temperature, and phenological stages (except flowering) with abundance of *D. durbanensis* were also significant (Table 3.8). Compared with vegetative stage, flowering stage (Exp [-0.03] = 0.97) and fruit setting (Exp [1.37] = 3.93) stages are likely to cause higher abundance of *D. durbanensis*. Abundance is also expected decrease with increase in maximum temperature (Exp [0.127] = 1.13 relative humidity (Exp [0.07] = 1.07) and rainfall (Exp [-0.01] = 0.99). Increase in minimum temperature is also likely to increase abundance of *D. durbanensis* (Exp [0.22] = 1.24).

Table 3.8: Estimates for Poisson regression of infestation rate of *D. durbanensis* as affected by host phenology and weather

Term	Estimate	SE	Chi square	P-Value
Intercept	-15.65456	13.538436	1.3350811	0.2479
Flowering	-0.033711	0.4583771	0.0054086	0.9414
Fruiting	1.3761204	0.400123	14.404737	0.0001*
After fruiting	-1.259726	0.7890721	4.0273453	0.0448*
Maximum temperature	0.1276489	0.3438987	0.1369444	0.7113
Minimum temperature	0.224772	0.2389676	0.8680143	0.3515
Rainfall	-0.015807	0.0044514	13.217102	0.0003*
Relative humidity	0.0758884	0.1027286	0.5437214	0.4609

** indicates significance, vegetative stage is the reference*

3.4 Discussion

This study reported spatial and temporal abundance of selected cucurbit infesters in Morogoro Region. Results showed significant interaction effects of season, agroecological zone and fruit fly species. Results also show abundance of *Z. cucurbitae* was higher than *D. bivittatus* and an *D. ciliatus* both at the plateau and mountainous zones.

According to Mwatawala *et al.* (2010) the occurrence of *Z. cucurbitae* in the Morogoro Region is limited to medium altitude due to its preference for warmer conditions. However, the previous study was based on trapping in fruit orchards and much of the insects came from wild rather than cultivated cucurbitaceous hosts. In the present study, commercial hosts were purposely established and maintained under irrigation for extended periods of the year. This also contrary to observation in Reunion islands that relative abundance of *Z. cucurbitae* was lowest in high altitude sites (above1000 m), where *D. demmerezi* was the most prevalent species (Vayssieres *et al*., 2008). *Z.*

cucurbitae is found at low and medium altitude in the Reunion Island where it competes with the Ethiopian cucurbit fly *D. ciliatus*. However, a later study by Deguine *et al*. (2011) in Reunion islands reported that *Z. cucurbitae* was the least abundant species compared to *D. ciliatus* and *D. demmerezi*. In the present study, *D. ciliatus* had lower abundance than *Z. cucurbitae, D. bivittatus* an *D. durbanensis* while *D. demmerezi* was not recorded.

Zeugodacus cucurbitae was the dominant species especially during the April – May period (main rainy season) at the plateau zone. A previous study by Mwatawala *et al.* (2010) in Morogoro reported that the peak populations of *Z. cucurbitae* were recorded during the dry period, when temperatures and relative humidity were low. Laskar and Chatterjee (2010) found that during warm and rainy months (June, July, August, at 25-37^{o}C), *Z. cucurbitae* was more active as compared to that of dry and winter (December, January, February 8-23^{o}C) months. Further to this, Kumar *et al*. (2008) reported peak population of *Z. cucurbitae* in in India during the month of August.

The current study used Poisson regression to determine association between weather parameters and phenology with abundance of cucurbit infesters. Abundance of cucurbit infesters with rainfall, relative humidity, minimum temperature, maximum temperature and flowering stage. Ganie (2013) found that population of cucurbit infesters was significantly correlated with the minimum and maximum temperature. Trap catches of *Z. cucurbitae* in India was significantly and positively correlated with relative humidity (Kumar *et al.*, 2008).

Seasonal abundance of fruit flies like other insects is modulated by both biotic and abiotic factors as well as human intervention such as application of insecticides. Key factors determining abundance include availability and abundance of hosts, crop phenology, competition, natural enemies, life history strategies adopted by a pest, and weather factors like temperature and humidity. Furthermore, changes in individual success in finding and exploiting resources, mating and reproducing, and avoiding mortality agents determine numbers of individuals, their spatial distribution, and genetic composition at any point in time (Schowalter, 2006; 2011). Like other insects Tephritid's distribution and abundance are markedly structured by various biotic and abiotic factors which include temperature, humidity, host fruit and natural enemies, and these have direct effect on species themselves as well as an indirect effect by modulating interspecific competition (Duyck *et al*., 2004; Duyck *et al*., 2006). Invaders like *Z. cucurbitae* are generally assumed to be r-strategists, characterized by rapid population growth and colonization of new habitats. However exotic invaders tend to be more competitive (Byers, 2000; Petren and Case, 1996) and they are able to quickly dominate the indigenous species. Interference competition implies that a more aggressive species gains access to a resource to the detriment effects to the others. Higher abundance of *Z. cucurbitae* at both agroecological zones can be attribute to an increase of various factors including competition.

3.5 Conclusion

The study successfully highlighted the spatial and temporal dynamics of cucurbit infesters across the plateau and mountainous zone of the Morogoro region. The study showed higher abundance of *Z. cucurbitae* at both zones compared with other cucurbit infesters. Management programs against cucurbit infesters should be centered on *Z. cucurbitae* regardless of the agroecological zone. Management should be more intensive during the main rainy season since results of this study showed higher abundance of *Z. cucurbitae* during the main rainy season.

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CHAPTER FOUR

Host preference of fruit flies (Diptera: Tephritidae) among selected cucurbitaceous vegetables in Morogoro, Eastern-Central Tanzania

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To be submitted to: Journal of Insect Science (OXFORD)

4.0 Abstract

Incidence and infestation of cucurbit infesters among selected cucurbit crops was studied in ten cucurbit plots established across the plateau zone and mountainous zone of the Morogoro region from March to November 2020. The plots were divided into three subplots in which three cucurbit crop species; cucumber (*Cucumis sativus*), watermelon (*Citrullus lanatus)* and squash *Cucurbita moschata*) were planted. Sampling was done by harvesting cucurbit fruits weekly for five consecutive weeks in each cucurbit growing season. Between five and 20 fruits were collected into separate plastic containers and then transported to the established rearing unit at SUA horticulture Unit. Results showed significant differences in infestation rates among three dominant fruit fly species ($P<0.05$). The effects of host, altitude, season and fruit fly interactions on infestation rates were also significant ($P<0.05$). Squash was the most preferred host by *Zeugodacus cucurbitae,* watermelon was the preferred host for *Dacus vertebratus* and squash was the preferred host for *Dacus ciliatus.* Incidence of *Z. cucurbitae* was significantly associate with host crops ($P<0.05$). On other hand incidence of *D. vertebratus* was significantly associated host and altitude ($P<0.05$). Likewise, incidence of *D. ciliatus* was significantly associated with host, altitude and season (0.05).

Key words: Host use, incidence, infestation, fruit flies and cucurbit crops.

4.1 Introduction

Cucurbitaceous crops are a source of nutrition among populations in Africa and the world. Popular crops include watermelon *Citrullus lanatus*, cucumber *Cucumis sativa* and pumpkin *Cucurbita* sp. Apart from being a source of human food, cucurbits are used as animal feed supplements, raw materials for biodiesel production and a source of ethno-medicines. They are a source of income for smallholder farmers who earn their livelihood by selling their produce in local urban markets. Production and corresponding export volumes of cucurbitaceous crops from Africa are generally low.

Production of cucurbits is affected by various factors including insect pests and diseases. Fruit flies among the major pests affecting cucurbit production. Major pests mainly belong to genera *Zeugodacus* and *Dacus*. They include *Zeugodacus cucurbitae* (Coquillet), *Dacus ciliatus* L., *D. punctatifrons* (Bigot) *and D, vertebratus* Bezzi (De Meyer and Virgilio, 2015; Tanga and Rwomushana, 2016). Amongst the tephritids attacking vegetables, *Z. cucurbitae* followed by *D. ciliatus* dominate the indigenous *Dacus* and *Ceratitis* species (Mwatawala *et al*., 2010; Tanga and Rwomushana, 2016). Host range and infestation rates of most cucurbit infesters have been less studied especially in the Afrotropical region. Most studies on hist range and preference focused on *Z. cucurbitae* (Dhillon *et al*., 2005; Vayssieres *et al.*, 2007; Mwatawala *et al.* 2009; 2010; 2015; Krishna-Kumar *et al.*, 2008; De Meyer and Virgilio, 2015; Tanga and Rwomushana 2016; McQuate *et al.*, 2017; Ryckewaert *et al.*, 2009). Developmental biology of *Z. cucurbitae* among preferred hosts was reported by Mkiga and Mwatawala (2015).

Genera *Dacus* and *Zeugodacus* are composed of oligophagous species, specialised on hosts from the family Cucurbitaceae. *Zeugodacus cucurbitae* is an exception as it has been reported from hosts belonging to other families like Solanaceae, Rutaceae, Passifloracea, Caricacea and Anacardiacea (De Meyer and Virgilio, 2015). Knowledge of the host range of vegetable-infesting fruit fly species throughout their geographic ranges (especially in Africa) is generally limited (Tanga and Rwomushana, 2016). Detailed studies on their feeding requirements and habits are urgently required (Manrakhan, 2016).

Agroecology has been proposed as the sound method of management of cucurbit infesters (Deguine *et al*., 2015). These studies require knowledge of among other things, species composition, host range and pattern of infestation among hosts in different agroecological zones. The aim of this study was to determine host preference of cucurbit infesters among selected cucurbitaceous hosts viz watermelon, cucumber and pumpkin in different agroecological zones. Information generated from this study will be used in developing agroecological approaches against major cucurbit infesters in Morogoro Region, eastern Central Tanzania.

4.2 Materials and Methods

4.2.1 Study site

Studies on the seasonal abundance of cucurbit infesting flies were conducted from March to November 2020 in Morogoro Region in eastern-central Tanzania. Morogoro Region is located in the transition zone between the bimodal and unimodal rainfall belts at S5°58’-S10°0’South and E35°25’- E38°30’ East (URT, 2002). Study sites were selected between October and November 2019 within plateau and mountainous zones of Morogoro (Table 4.1). River valley and basins zone was excluded because of dominance of flooded paddy fields.

Table 4.1: Agroecological zones of Morogoro Region

Zone	Characteristics
Mountainous zone	Altitude: > 600 meters asl; Average rainfall: 800 mm – 2500 mm p.a
Plateau	Altitude: 300-600 meters asl; Average rainfall: 700 mm – 1200 mm p.a
River valleys and basins	Altitude: < 300 meters asl; Average rainfall: 900 mm – 1400 mm p.a

Source: URT 2002.

Ten experimental plots were established in ten different localities within two agroecological zones namely, the plateau and mountainous zones of Morogoro (Table 4.2). In each agroecological zone five experimental plots located at least 1 km apart from each other were established. Selected hosts were cucumber (*Cucumis sativus* L.), variety "Ashley", and watermelon (*Citrullus lanatus* [Thunb.] Matsum. & Nakai), variety "Sugar baby" and squash (*Cucurbita maxima* L.) variety "Waltham". Cucumber, watermelon and squash were each planted on a 0.25-acre (1012 m^2) plot at a spacing of 50 cm x 60 cm, 1 m × 1.5 m and 1 m × 1.5 m respectively.

Table 4.2: Experimental field locations in two agroecological zones of the Morogoro region

Location of field plots in two different Agro ecological zones			
Location	**Coordinates**	**Altitude**	
SUA Horticulture Unit (HT)	S06˚50'41.4" E37˚39'43.3"	524 m	Plateau zone
SUA Crop Museum (CM)	S06˚51'00.53" E37˚39'17.90"	528 m	
SUGECO (SG)	S06˚50'22" E37˚38'42.2"	511 m	
SUA Mazimbu (MZ)	S06˚47'26.208" E37˚38'7.926"	486 m	
SUA Mafiga (MF)	S06˚50'22.764" E37˚37'53.46"	503 m	
Morning Site (MS)	S06˚53'17.9" E37˚40'14.93"	1274 m	Mountainous zone
Mkumbulu (MK)	S06˚52'24.2" E37˚40'21.5"	1105 m	
Ruvuma (RV)	S06˚52'34.6" E37˚40'3.7"	995 m	
Kifuru (KF)	S06˚53'32.1" E37˚40'9.5"	1418 m	
Mgola (MG)	S06˚51'41.4" E37˚40'4.3"	1084 m	

4.2.2 Fruits sampling and rearing

During the peak of fruiting season, a minimum of 10 fruits were randomly collected from each plot. Fruit sampling followed the methodology described by Copeland *et al.* (2002). Fruits were transported to the rearing facility in the horticulture unit at Sokoine University of Agriculture (SUA) Morogoro. The fruit were counted, weighted and placed in the rearing cage as described in by Copeland *et al.* (2002). The holding cages were made of two rectangular transparent plastic containers of 23 by 16 cm top and 21 by 13 cm bottom. One container is perforated with ellipsoid holes at the bottom to prevent the fruit from clogging the holes and allowed mature larvae to fall into the soil after leaving the host fruit and the top cover with the polythene mesh for ventilation propose, was tightly fitted on top of the second container that contain a thin layer of moistened and sterile sand soil to hold exudates dripping from rotting fruit. Sandy soil served as the pupation substrates of the popping larvae as they left the fruit. Emerged adults were removed and handled following methods described by White and Elson-Harris (1994). The procedure of fruit flies rearing was outlined by the African Fruit Flies Initiative (Ekesi, 2006). After 10 to 12 days of incubation at room temperature of 23 -25°C container was examined daily for adult fruit flies until no more fruit flies emerged. The emerged fruit flies were removed from rearing cages by aspirator and preserved in vials containing alcohol of 70% for identification.

4.2.3 Data collection and identification

The number of each emerged fruit fly species were recorded from each fruit sample. Infestation rate was established as the number of emerged adult fruit flies per unit weight of sampled fruit species. Incidence was expressed as percentage of infested samples. Incidence and infestation rate parameters were determined using methods described by Cowley *et al.* (1992) and Copeland *et al.* (2002). Fruit fly morphological identification to species level was conducted at the Sokoine University of Agriculture (SUA) entomology laboratory with the aid of binocular stereomicroscope using keys and characters presented by White and Elson-Harris (1994), White (2006), Ekesi and Billah (2007) and electronic keys by Virgilio *et al*. (2014). For further identification and confirmation some specimens were sent to the Royal Museum for Central Africa (RMCA).

4.2.4 Data analysis

Analysis of Variance (ANOVA) was used to determine effects of host, agroecological zone, cropping season and fruit fly species on infestation rate of the dominant cucurbit infesters. Weekly infestation rates during a growing period were averaged and used in ANOVA. Logistic regression was used to determine association between altitude, season and host on incidences of fruit fly species. In this case, incidence was recorded as presence or absence of a fruit fly species from a fruit sample.

4.3 Results

3.3.1 Incidence and infestation rates of fruit flies among cucurbitaceous hosts

Table 4.3 shows number of positive samples for the five species of cucurbit infesters. *Zeugodacus cucurbitae* had highest number of infested samples compared to the other four species. On overall, percentage of positive samples for most fruits was more than 90. Table 3.3 shows the incidence and infestation rates of fruit fly species from the three cucurbitaceous hosts. A total of 6 663 flies emerged from three hosts at mountainous zone, while 6 886 flies were recovered from fruits collected from the plateau zone. Species *D. vertebratus* was only recovered from fruits sampled from high altitude, while species *D. punctatifrons* was recovered from fruits collected from low altitude only. Generally, the highest at both low and high attitude incidence and infestation rates were by *Z. cucurbitae* followed by *D. vertebratus* among all three hosts (except squash). The lowest incidence and infestation rate were by *D. punctatifrons* (Table 4.3).

Table 4.3: List of hosts indicating positive samples for the emerged cucurbit infesters

Agroecological zone	Host Crop	Total number of samples	No. of fruits	Weight of fruits (g)	# of positive samples	% of positive samples	# +ve *Z. cucurbitae*	# +ve *D. vertebratus*	# +ve *D. ciliatus*	# +ve *D. bivittatus*	# +ve *D. punctatifrons*
Mountainous zone	Watermelon	50	798	13696.8	47	94	47	10	7	19	2
	Cucumber	50	894	40173.5	48	96	47	3	3	16	2
	Squash	50	1314	10390.6	47	94	47	0	3	13	1
Plateau zone	Watermelon	50	804	23948.2	48	96	43	38	14	11	0
	Cucumber	50	824	41740.6	49	98	49	20	11	2	0
	Squash	50	1259	17834.9	47	94	46	19	32	5	1

Table 4.4: Incidence and infestation rates of cucurbit infesters among three cucurbitaceous hosts

	Agroecological zone	Mountainous			Plateau		
	Crop → Species ↓	Watermelon	Cucumber	Squash	Watermelon	Cucumber	Squash
No. emerged	*Z. cucurbitae*	1834	2335	3171	1239	1599	2235
	D. bivittatus	69	91	75	53	9.00	17
	D. ciliatus	13	5.00	5.00	74	33	222
	D. punctatifrons	4.00	2.00	1.00	0.00	0.00	1.00
	D, vertebratus	47	11.0	0.00	1174	114	116
Infestation rate	*Z. cucurbitae*	133.90	0.06	0.31	0.05	0.04	0.13
	D. bivittatus	5.04	2.27	7.22	2.21	0.22	0.95
	D. ciliatus	0.95	0.12	0.48	3.09	0.79	12.45
	D. punctatifrons	0.29	0.05	0.10	0.00	0.00	0.06
	D, vertebratus	3.43	0.27	0.00	49.02	2.73	6.50
Incidence	*Z. cucurbitae*	0.94	0.94	0.94	0.86	0.98	0.92
	D. bivittatus	0.38	0.32	0.26	0.22	0.04	0.1
	D. ciliatus	0.14	0.06	0.06	0.28	0.22	0.64
	D. punctatifrons	0.04	0.04	0.02	0.00	0.00	0.02
	D, vertebratus	0.20	0.06	0.00	0.76	0.40	0.38

Results showed significant differences on infestation rates among all treatments. Furthermore, the effects of all interactions were significant (Table 3.4). These results imply that all the infestation rate would depend on combined effects of host, altitude, season and fruit fly species.

Infestation rate by *Z. cucurbitae* was significantly higher in squash than watermelon and squash at the mountainous zone. Infestation rates of other species at the mountainous zone were generally low. At the plateau zone, *Zeugodacus cucurbitae* had significantly higher infestation rates in squash compared with *D. ciliatus*. Furthermore, *Z. cucurbitae* and D. *vertebr*atus had significantly higher infestation rates in watermelon than *D. ciliatus*. Infestation rates of cucurbit infesters in cucumber were not significantly different (Figure 4.1).

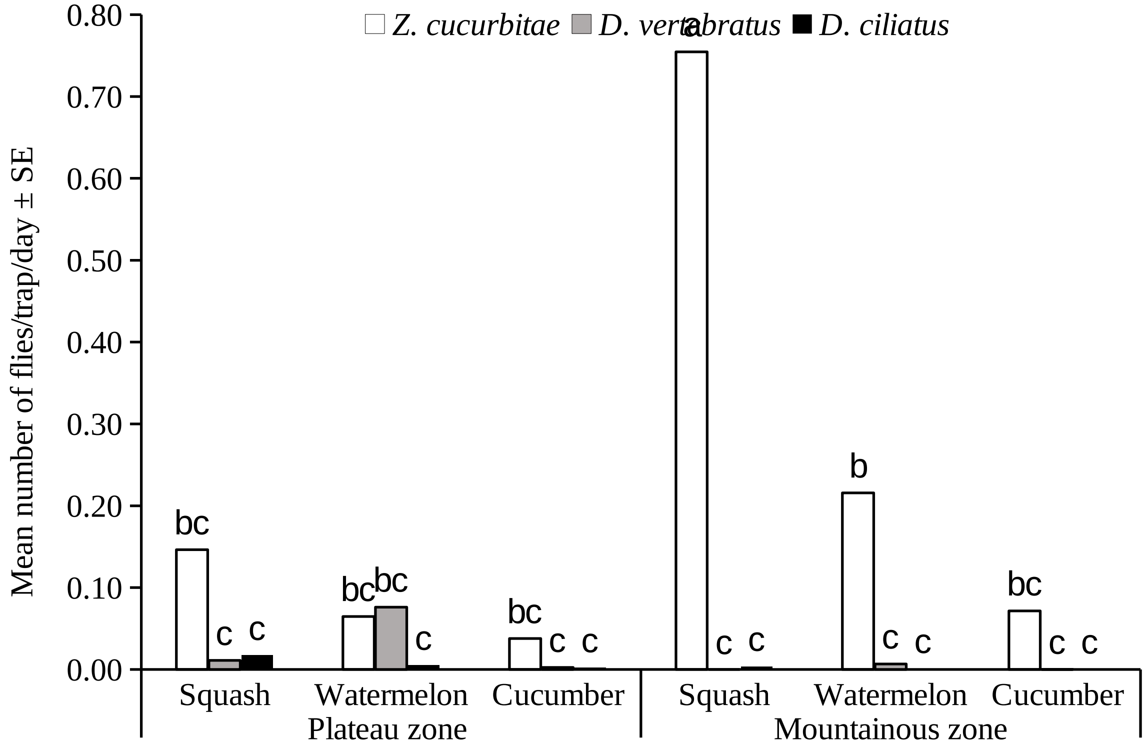

Figure 4.1: Mean Infestation rates of major cucurbit infesters among three hosts grown in plateau and mountainous areas

Results showed significant differences on infestation rates among all treatments. Furthermore, the effects of all interactions were significant (Table 4.5). These results imply that all the infestation rate would depend on combined effects of host, altitude, season and fruit fly species.

Table 4.5: ANOVA results on effects of host, altitude, season and fly species on infestation rates

Source	df	SS	F-Ratio	Prob > F
Crop species (C)	2	0.8746233	18.8230	<.0001*
Agroecological zone (AZ)	1	0.3971134	17.0928	<.0001*
Cropping Season (S)	2	0.3026026	6.5124	0.0018*
Fly species (F)	2	2.5150618	54.1273	<.0001*
C × AZ	2	0.4694361	10.1029	<.0001*
C × S	4	0.2349427	2.5281	0.0417*
C × F	4	1.7534813	18.8686	<.0001*
AZ × C	2	0.3141192	6.7602	0.0014*
AZ × F	2	1.1920458	25.6543	<.0001*
S × F	4	0.4289235	4.6155	0.0014*
C × AZ × S	4	0.2797991	3.0108	0.0191*
C × AZ × F	4	0.9307789	10.0158	<.0001*
C × S × F	8	0.5172079	2.7827	0.0060*
AZ × S × F	4	0.7480259	8.0492	<.0001*
C × AZ × S × F	8	0.5320389	2.8625	0.0048*

** indicates significance*

4.3.2 Association between altitude, season, host with incidence of cucurbit infesters

Results showed significant association between hosts with incidence of *Z. cucurbitae* (Table 3.6). Compared with squash, watermelon is expected to have less incidence of *Z. cucurbitae* (Exp [-0.05] = 0.95). On the contrary, cucumber is likely to have higher incidence of *Z. cucurbitae* than squash, although this association is not significant. Associations between cropping period and agroecological zone with incidence of *Z. cucurbitae* were not significant.

Table 4.6: Estimates for Logistic regression of incidence of *Z. cucurbitae* as affected by altitude, season and host

Term	Estimate	SE	Chi square	P-Value
Intercept	-0.091742	0.0147032	38.931953	<.0001*
Low altitude	-0.002182	0.0146689	0.0221625	0.8817
June - August	-0.006719	0.020292	0.1125648	0.7372
September - November	-0.021223	0.0212911	1.110794	0.2919
C. lanatus	-0.05403	0.0243776	6.1032401	0.0135*
C. sativus	0.0266147	0.0194341	1.7857772	0.1814

** indicates significance, Reference points are High altitude, March - May and C. maxima*

Results further showed significant association between hosts, altitude with incidence of *D. vertebratus* (Table 3.7). Watermelon is likely to be higher incidence of *Z. cucurbitae* than squash (Exp [0.52] = 1.69). Likewise, cucumber is likely to have a higher incidence of attacks than squash (Exp [-0.24] = 0.79). Incidence of *D. bivittatus* is likely to be higher in the plateau zone (Exp [0.98] = 2.67).

Table 4.7: Estimates for Poisson regression of incidence of *D. vertebratus* as affected by altitude, season and host

Term	Estimate	SE	Chi square	P-Value
Intercept	-1.714945	0.1278626	179.8926	<.0001*
Low altitude	0.9808194	0.1233019	130.43598	<.0001*
June - August	-0.102821	0.075451	2.1468312	0.1429
September - November	0.0658242	0.0639026	0.9535359	0.3288
C. lanatus	0.5246241	0.0772788	46.424134	<.0001*
C. sativus	-0.240171	0.1086935	5.4652565	0.0194*

** indicates significance, Reference points are High altitude, March - May and C. maxima*

Results showed significant association between hosts, altitude, and cropping period with incidence of *D. ciliatus* (Table 4.8). Compared with squash, cucumber is expected to have less incidence of *D. ciliatus* (Exp [0.287] = 0.7). Higher incidences of *D. ciliatus* are expected in the plateau zone (Exp [0.62] = 1.86) and during dry wet season (Exp [0.248] = 1.28).

Table 4.8: Estimates for Poisson regression of incidence of *D. ciliatus* as affected by altitude, season and host

Term	Estimate	SE	Chi square	P-Value
Intercept	-1.514502	0.0998638	229.99767	<.0001*
Low altitude	0.6206956	0.0926161	61.604961	<.0001*
June - August	0.110984	0.0976025	1.2160756	0.2701
September - November	0.248114	0.0869852	8.1043993	0.0044*
C. lanatus	-0.087874	0.1044605	0.735657	0.3911
C. sativus	-0.287402	0.1131046	7.4536633	0.0063*

** indicates significance, Reference points are High altitude, March - May and C. maxima*

4.4 Discussion

Results of this study showed that *Z. cucurbitae*, followed by *D. vertebratus* and *D. ciliatus* and were the dominant infesters of the three studied hosts. Infestation rates of *Z. cucurbitae* among all hosts were significantly higher than *D. ciliatus* and *D. vertebratus* at the mountainous zone. Same was observe in squash at the plateau zone, although differences between *Z. cucurbitae* and *D. vertebratus* were not significant. A study by Kambura *et al*. (2018) in coastal Kenya found that *Z. cucurbitae* was the most destructive fruit fly followed by *D. ciliatus* and *D. bivittatus*. A previous study Mwatawala *et al*. (2015) reported higher infestation rate of *Z. cucurbitae* in watermelon than cucumber and pumpkin while Kambura *et al*. (2018) reported watermelon and cucumber as the most preferred hosts of *Z. cucurbitae D. bivittatus* and *D. ciliatus* in in coastal Kenya (Kambura *et al*., 2018). Vayssières (1999).

D. ciliatus dominated in the cultivated hosts which were cultivated above the altitudinal limit of *Z. cucurbitae* (600m during the cold season and up to 1200 meters during the hot season) while *Zeugodacus cucurbitae* dominated on watermelon and cucumber grown on low altitude areas. This study however showed dominance of *Z. cucurbitae* of *D. ciliatus* in both low and high altitude agroecological zones.

Results of the present study showed that up to 146 flies emerged per kilogram of fruits, and incidence as high as 93% was recorded. Dhillon *et al*. (2005) noted that the extent of losses inflicted by *Z. cucurbitae* vary between 30% and 100%, depending on the cucurbit species and environmental conditions in different parts of the world. Sapkota *et al*. (2010) in their work on the damage assessment and management of cucurbit fruit flies in spring-summer squash conducted in Nepal concluded that *B. cucurbitae* causes about 50% losses in squash yield under farmers' fields in uncontrolled conditions. This is lower than 96% incidence of *Z. cucurbitae* in squash that was recorded in the present study. Pradhan (1976) reported 19.4 - 22.1% yield losses in cucumber caused by *Z. cucurbitae* from the field experiments in Nepal. These figures are lower than incidences of 92% and 93% recorded in the plateau and mountainous zones respectively recorded in the present study.

Other studies in India reported maximum fruit fly infestation of *D. ciliatus* 73.83 % on cucumber and 63.31 % on pickling cucumber (Manoj *et al*., 2017). These were much higher than those observed in the present study. Maximum *Z. cucurbitae* emergence of 431.97/ Kg fruit was of cucumber was much higher the 71.53/ kg fruit that was recorded in this present study. Manoj *et al.* (2017) reported that in the non-choice test, bitter gourd was most preferred host by *Z. cucurbitae* followed by the pumpkin, brinjal (*Solanum melongena* L.), cucumber and muskmelon (*C. melo*). These hosts were however not included in the current study. Results by Shahzadi *et al*. (2019) showed that that bitter gourd was most preferred vegetable plant host.

Logistic regression was used to determine the association between hosts with incidence of cucurbit infesters. Results showed that squash was likely to have higher incidences of attacks by *Z. cucurbitae* compared to watermelon. On the contrary, cucumber had higher chances of being attacked by *Z. cucurbitae* than *squash*. A previous study by (Mwatawala *et al.*, 2009) showed that highly preferred cucurbit hosts of *Z. cucurbitae* were cucumber (*Cucumis sativus*), melon (*Cucumis melo* L.) and watermelon (*C. lanatus*), while *Momordica* cf *trifoliata* L. was the most important wild host. *Z. cucurbitae* appeared to dominate most indigenous cucurbit infesters, with the exception of *D. ciliatus* which was still dominant in some cucurbitaceous spp. However, infestation rates were not significantly different among fruits from natural and semi-natural conditions. *Dacus vertebratus* had higher incidence in *C. lanatus* than *C. maxima* while *D. ciliatus* was likely to have higher incidence in *C. maxima* than *C. lanatus* and *C. sativus*.

Results of this study further showed dominance of the invasive *Z. cucurbitae* over native *Dacus* species as an infester in cucurbit hosts in Africa. Of particular interest is higher incidence and infestation rate of *Z. cucurbitae* in the mountainous zone, which is a higher altitude area. This is contrary to a study by Vayssières (1999) as cited by De Meyer and Virgilio (2015) that showed dominance of *Z. cucurbitae* in hosts grown in low altitude areas. A previous study Mwatawala *et al.* (2010) that showed low of abundance *Z. cucurbitae* at higher elevations in Morogoro, Tanzania. Preference for warmer periods (characteristic of low altitude areas) has also been reported by Vargas *et al*. (1989) and Vayssières (1999) as cited by De Meyer and Virgilio (2015) in La Réunion. According to De Meyer and Virgilio (2015) the relationship between biotic and abiotic factors that can have an impact on the host range in different African populations, is currently poorly known and requires further investigation. This study was limited to three commercial hosts. Other studies showed expansion of host range of *Z. cucurbitae* to non-cucurbitaceous hosts.

4.5 Conclusion

Fruit fly species had significant different infestation rates among the cucurbit crops. Type of cucurbit crops, altitude and season were the influential factors for incidence and infestation rates among the fruit fly species. Among the cucurbit crops, the *Cucurbita maxima* was the most preferred host by *Z. cucurbitae*, *C. lanatus* for *D. vertebr*atus and squash was the most preferred host for *Dacus ciliatus*. In general, these findings imply that any control program should focus at suppression of fruit fly population on the hosts with high incidence and infestation rates with respect to particular fruit fly species. In addition, the suppression program of fruit flies should be conducted at the start of the fruit season since higher infestation was reported at that stage of crops phenology.

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CHAPTER FIVE

5.0 General Conclusion and Recommendation

5.1 Conclusions

Fruit flies are among the major constrains for cucurbits production in Tanzania. They inflict high economic losses and influence marketability of important fruits and vegetables. These flies warrant for immediate control measures and action researches. Therefore, this study documents the ecological community (diversity, species composition and abundance) as well as the host preferences of cucurbit infesters associated with cucurbitaceous production systems in the Morogoro region.

- In the two agroecological zones of the Morogoro region, where the study was undertaken, the mountainous zone recorded the highest numbers of cucurbit infesters (67.5%) compared to the Plateau zone (32.5%).
- Different in agroecological zones, season and trapping weeks showed significance effects on abundance among the three dominant species of fruit flies.
- In addition to temperature, rainfall and relative humidity, crop phenology had significance association with the abundance among the three dominant species of fruit flies.
- Among the 21 species of fruit flies identified as infesters of cucurbit crops, *Zeugodacus cucurbitae* accounted for 83.4% of the total specimens collected and species from genera Dacus (*D. bivittatus, D. punctatifrons, D. vertebratus, D. ciliatus, D. telfaireae, D. durbanensis, D. humeralis, D. xanthopterus, D. frontalis, D. hyalobasis, D. woodi, D. ceropegiae, D. annulatus, D. chiwira, D. pulchralis, D. nr brevistriga, D. longistylus, D. sphaericticus* and

Dacus spp) and Bactrocera (*B. dorsalis*) constituted the remaining 16.6% of the total specimens collected.

These species therefore, should be recognized as among the devastating species of cucurbit crops, thus requires immediate control if the production of cucurbit production is to be realized in the Morogoro region.

5.2 Recommendations

Results of this study seem to suggest that among the fruit fly species, *Zeugodacus cucurbitae*, *D. bivittatus, D. punctatifrons*, *D. vertebratus*, *D. ciliatus, D. telfaireae* and *B. dorsalis* represented the most devastating group of cucurbit infesters. Therefore, we recommend that,

- Any immediate control measures should focus to suppress their population by considering the agroecological zones, crop phenology and season.
- The study also calls for more studies should be conducted to explore the distribution as well as their present status in different farming systems and landscapes.
- Such study will not only provide sufficient information to stakeholders regarding the diversity and abundance of fruit flies but also will explore the potential management practices sustainable fruit flies’ control.

APPENDICES

Appendix 1: **Meteorological data on Rainfall, Temperature and Relative humidity from March to November 2020 in Morogoro, Tanzania.**

Parameters	Rainfall	Maximum Temperature	Minimum Temperature	Relative Humidity
March	266.5	32.1	22	86
April	178.6	28.8	21.7	85
May	41	27.2	20	83
June	1	28	17.4	78
July	32.7	26.7	16.1	77
August	8.6	28.5	17	74
September	0.6	29.6	18.1	72
October	0.4	31	21	70
November	1.5	31.5	21.7	70