DIVERSITY AND DISTRIBUTION OF FRUIT FLIES (DIPTERA: TEPHRITIDAE) ATTACKING PUMPKIN [*Cucurbita maxima* Duchesne ex Lam.] IN ZAMBIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE.

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ABSTRACT

The study on the diversity and distribution of fruit flies (Diptera: Tephritidae) in Zambia were carried out during the 2010/ 11 cropping season (October to April). Three sites were selected in three agro-ecological regions. The aim of the study was to: establish the diversity of cucurbits infesters; assess infestation rate of fruit flies attacking pumpkin in Central Zambia; assess distribution and seasonal abundance of cucurbits infesters; determine the influence of climate on abundance of cucurbit infesters; and predict the potential distribution of *Bactrocera cucurbitae* in Zambia. Data on infestation rate were collected by random pumpkin fruit sampling in Central Zambia and rearing during the 2010/11 cropping season. Fruit flies collected from each site were identified to determine the species composition and diversity. The data on population dynamics were collected by installing cue lure baited traps at selected sites in three agro-ecological zones of Zambia. The influence of abiotic factors on population fluctuation was determined using simple correlation and linear regression models. CLIMEX© software package was used to predict the distribution potential of *B. cucurbitae* in Zambia. The study focused on fruit flies of economic importance that attack pumpkin. A total of 11 species representing the genera *Dacus* and *Ceratitis* were recorded in Central Zambia with Chilanga showing the highest diversity. The infestation for *Dacus ciliatus* was the highest compared to *Dacus bivittatus* and *Dacus vertebratus*. The dominant species in all the agro-ecological zones was *Dacus bivittatus* with insignificant Seasonal abundance differences. This was attributed to the availability of host fruits throughout the year. Reliable risk map for potential geographical distribution of *B. cucurbitae* was generated. An integrated systems approach for the management of fruit flies has been suggested.

DECLARATION

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

.... 19 /11 /2012 ....

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The above declaration is confirmed

.... 22/11/2012 ....

Prof. M. W. Mwatawala Date

(Supervisor)

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DEDICATION

This thesis is affectionately dedicated to my late parents who sacrificed for my education - Mr. Alexander Mwape and Mrs. Dorothy Katebe Mwape. I will always dearly miss you. My late brother – Ngosa Mwape, for encouraging me to work hard. I will always greatly miss you. My wife – Fainess Lumbwe (PhD), for the love. I will always cherish you. My brothers and sisters - whose unfailing love and affection has always been a source of inspiration. It's a blessing to have you all in my life.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	-	per cent
£	-	Pound
A$	-	Australian Dollar
AEZ	-	Agro-ecological zone
AGRA	-	Alliance for Green Revolution in Africa
AIDS	-	Acquired Immune Deficiency Syndrome
ANOVA	-	Analysis of variance
asl	-	above sea level
CL	-	Cue lure
COPE	-	Centre of Phytosanitary Excellence
CPHST	-	Center for Plant Health Science and Technology
DVDP	-	Dichlorovinyl dimethyl-phosphate
EI	-	Ecoclimatic Index
et al	-	and others
FAO	-	Food and Agriculture Organisation
Fig	-	Figure
g	-	gram
GART	-	Golden Valley Agriculture Research Trust
GI	-	Growth Index
ha^{-1}	-	per hectare
HIV	-	Human Immune Virus
IAEA	-	International Atomic Energy Agency
ID	-	Coefficient of distribution

IPPC	-	International Plant Protection Convention
ITCZ	-	Inter-Tropical Convergence Zone
km^2	-	Square kilometre
LDC	-	Least Developed Country
MoH	-	Ministry of Health
m	-	metre
mm	-	milimeter
NNP	-	National Nutrition Policy
^0C	-	Degrees Centigrade
RH	-	Relative Humidity
SIT	-	Sterile Insect Technique
sp	-	species
SUA	-	Sokoine University of Agriculture
US$	-	United States Dollar
UK	-	Unite Kingdom
UP	-	University of Pretoria
WTO	-	World Trade Organisation
ZARI	-	Zambia Agriculture Research Institute

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The access of all people, at all times, to safe, nutritious and healthy fruits to maintain an active life is critical. In the sub-Saharan Africa, the rapid population growth and progressive urbanisation has resulted into increasing rates of malnutrition and vitamin deficiencies in large sectors of rural and urban populations (WHO, 2002). This, along with increasing awareness of the nutritive value of fruits and the increased purchasing power of affluent segments of local populations translates into increased domestic demand for fresh fruits. In addition, the demand for quality tropical fruits in Europe, America and Japan is also growing. The above factors, combined with increasingly liberal global trade arrangements, have created new and lucrative production and trade opportunities in the fresh fruits and vegetables market.

Increased international trade of agricultural commodities and movement of people have brought increased risk of introduction of exotic plant pests of quarantine importance. Such introductions necessitate transparent mechanisms and state of the art analysis to approve or normalize trade (Sequiera, 2002).

Exportation of plants and plant products from countries previously free of these quarantine pests but which have experienced an introduction of such pests must demonstrate successful eradication of the incursion before they resume exporting fruits (Maelzer *et al.*, 2004; Macleod, 2006).

Horticulture is a fast growing agricultural sub-sector in Africa (Lux, 1999). Majorities of people in Southern Africa earn their livelihoods from horticulture. The production in sub-Sahara Africa is mainly by smallholder producers largely intended for local consumption in the rapidly expanding local and urban markets. Fruits and vegetables are essential to daily life as food, for food security, as means of employment, and as a source of income (Lux, 1999). However, the industry is threatened by the ravages of weather, diseases and insect pests. Amongst the various insect pests that limit the production and productivity of fruits and vegetables throughout the tropical and subtropical regions, are the fruit flies (Diptera: Tephritidae) (Hasyim *et al.*, 2006). The great majority of them belong to several genera namely *Anastrepha*, *Ceratitis*, *Bactrocera*, *Dacus* and *Rhagoletis*. About 35% of fruit fly species attack soft fruits, including many commercially important ones. Some species are of Afrotropical origin, however, alien species have also invaded the African continent. Among them is the Asian species *Bactrocera cucurbitae* (Coquillett), a major threat to cucurbit production with a wide distribution, India being considered as its native home (Dhillon *et al.*, 2005). It is a very serious insect pest throughout its native area. On the other hand, 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 (White and Elson-Harris, 1994). Although a lot of detection work is being conducted in most parts of Zambia on Asian Fruit fly (*Bactrocera invadens* Drew, Tsutra and White), little is known about the diversity and distribution of indigenous fruit fly species in Zambia, their spatial and temporal fluctuation and the damage caused to cucurbit production.

1.2 Justification

A country requires an effective and efficient application of phytosanitary measures in order to prevent the introduction and spread of plant pests from one geographical area to another. These measures must be applied in a transparent and non-discriminatory manner. Nevertheless, in the recent past, several invasive plant pest outbreaks have been reported to the International Plant Protection Convention (IPPC) indicating that the threat to the safety of our food production is more than a theoretical concern (Sequiera, 2002). The ecological impact of introduced invasive insect species is broad and unpredictable in the short term. Many of the effects are delayed because the impacts are on breeding system and competition in trophic areas. Therefore, observation must continue over a number of feeding and breeding systems. before the cumulative effects become clear and evident (Kenis *et al.* 2009). For example, it has been estimated that *B. cucurbitae* causes 30 – 100% yield loss depending on the cucurbit species and season of the year (Dhillon *et al.*, 2005). Thus management of tephritid fruit pests has become a worldwide problem (White and Elson-Harris, 1994; Malacrida *et al.*, 2007).

Market access for fresh fruits and vegetables can be maintained when a country is able to produce high quality pest free produce. In Zambia, the horticultural sector plays an important role in diversification of agricultural production systems and contributes substantially towards increased food security, better nutrition and poverty alleviation. However, presence of fruit flies in an area of production has resulted in a significant obstacle to improvement of nutrition and linking small scale farmers to regional/ international markets. Raising awareness about fruit flies and dissemination of

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The earliest known records about the presence of some *Dacus* species of economic importance in Zambia dates from 1910 (White, 2006). However, limited data are available on prevalence and relative importance of fruit flies attacking pumpkin. Studies to determine composition and diversity of cucurbit infesters in central Zambia have never been conducted. Information on species composition and diversity serve as a reference point for developing robust policies for domestic and international quarantine and for delivering pest management programs to practitioners at farm level. Species composition and species availability in an agroecosystem facilitate the formulation of an inclusive pest management strategy. Furthermore, pest status of cucurbit infesters has never been quantified. Pest status is derived from knowledge of pest-plant relationship and the crop response to pest injury.

In addition to the above, little is known on the distribution and population dynamics of cucurbit infesters in Zambia. Comprehension of distribution is of primary importance in management of pest species by relating their spatial distribution to crop injury they cause in a preferred agroecosystem. Population dynamics is a critical element in the biological information needed for pest management. Besides inherited characteristics of individuals of a species, Population dynamics seeks to explain the short-term and long-term changes in the size and age composition of the population of an insect or insects that are being studied, and the biological and environmental processes influencing those changes. Hence, provides for prediction of infestation and pest outbreaks so that this period can then be targeted for pest management intervention.

It also indicates environmental factors that might be exploited to reduce pest status as well as evaluating the efficacy of a pest management strategy employed (Pedigo and Rice, 2009).

Therefore, it is imperative to investigate the species composition, distribution and population dynamics of cucurbit infesters including the damage they cause. The knowledge gained from this study will facilitate in the development of appropriate pest management strategies and early warning system for pest outbreak to manage the risk posed by cucurbit infesters of economic importance on pumpkin production in Zambia. Furthermore, this will discourage farmers from the non-judicious application of insecticides that has led to a number of problems such as environmental pollution, food safety risks, development of pest biotypes, pest resurgence and secondary pest outbreaks.

1.3 Objectives

1.3.1 General objective

The main objective of the study was to establish actual and potential losses of pumpkin due to a diverse of fruit flies in Zambia.

1.3.2 Specific objectives

i. Determine species composition and diversity of cucurbit infesters attacking pumpkin in Central Zambia.

ii. Determine infestation rate of cucurbits infesters on pumpkin in Central Zambia.

iii. Assess distribution and seasonal abundance of cucurbit infesters in Zambia.

iv. Develop a model to predict potential distribution of cucurbit infesters in Zambia.

1.4 Research Questions

i. What is the distribution of fruit fly species attacking pumpkin in Zambia?

ii. What are the incidences and infestation rates of cucurbit infesters in pumpkin?

iii. How wide spread is the cucurbit infesters in Zambia?

iv. How does climate influence the seasonal abundance of cucurbit infesters?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Pumpkin, Cucurbita maxima Duchesne ex Lam

2.1.1 Description and origin

Cucurbits are annual plants with bushy or climbing and branching habits with vines usually 4 to 6 m long. They belong to the family Cucurbitaceae and order Violales which primarily comprises species consumed as food worldwide. The family consists of about 118 genera and 825 species. Although most of the cucurbits originate in the Old World, many species originate in the New World and at least seven genera are common in both hemispheres. There is tremendous genetic diversity in the family (CABI, 2007).

The genetic diversity in cucurbits extends to both vegetative and reproductive characteristics and considerable range in the monoploid (x) chromosome number including 7 (*Cucumis sativus*), 11 (*Citrullus* spp., *Momordica* spp., *Lagenaria* spp., *Sechium* spp., and *Trichosanthes* spp.), 12 (*Benincasa hispida*, *Coccinia cordifolia*, *Cucumis* spp. other than *C. sativus*, and *Praecitrullus fistulosus*), 13 (*Luffa* spp.), and 20 (*Cucurbita* spp.). The range of adaptation of cucurbits includes tropical and subtropical regions, arid deserts and temperate regions (Purseglove, 1984).

2.1.2 Ecology and development

Pumpkins and squashes (various *Cucurbita* spp.) are grown in the tropics from the lowlands up to 1500 m altitude. They are warm-season crops adapted to monthly mean temperatures of 18 to 27 °C. The most tolerant of low temperatures is *Cucurbita* *maxima* while *Cucurbita moschata* and *Cucurbita argyrosperma* are the least with *Cucurbita pepo* being intermediate. In temperate regions, *C. maxima* and *C. pepo* have long been cultivated. All four species are relatively insensitive to photoperiod, although both photoperiod and temperature influence the ratio of male to female flowers (long days and high temperatures favouring male sex expression). Pumpkins and squashes are not very demanding with respect to soil requirements. They can be cultivated on almost any fertile, well-drained soil with a neutral or slightly acid reaction (pH 5.5 to 7). They are drought-tolerant, requiring relatively little water, and are sensitive to water logging. Excessive humidity is harmful because of the development of leaf diseases, so none of the species does well in the humid tropics (CABI, 2007).

Germination is epigeal, seeds germinating about one week after sowing. They have extensive fibrous root systems and an indeterminate growth habit. Under suitable conditions, they will continue to grow indefinitely when the trailing stems are permitted to root at the nodes. Vines may reach a length of more than 15 m.

This does not apply to the bushy cultivars of *C. pepo* and *C. maxima*, which have short, semi-erect stems, due to short internodes. Flowering is more or less continuous, the ratio of male to female flowers being influenced by growing conditions. Pollination is effected by insects, mainly bees, so they are predominantly cross-pollinated. Squashes grown for the immature fruits produce the first harvest 7 to 8 weeks after planting and continue bearing for several months; those grown for mature fruits take 3 to 4 months until harvesting (CABI, 2007).

2.1.3 Economic importance of pumpkins

The fruit provides carbohydrates – 12 g, protein – 2 g, dietary fibre – 3 g, Calcium – 37mg, Magnesium – 22 mg, Potassium – 564 mg, Zinc 1 mg, Vitamin C- 12 mg and Vitamin E – 3 mg on a 100 g nutritional value basis to the human body besides being a source of income . Fresh pumpkin leaves are rich in calcium, protein and vitamin C. Dried leaves are high in protein and iron and moderately high in vitamin C (Migochi and Luchen, 1997), while seeds of pumpkins can be roasted as a snack and made into a paste like peanut butter. World production of cucurbits in 2003 was estimated at 17.4 million tonnes with Africa producing 1.8 million tonnes (CABI, 2007).

Fruits, leaves and flowers of *C. moschata*, *C. argyrosperma*, *C. maxima* and *C. pepo* are used as vegetables, and their seeds are consumed roasted as a snack food. There are numerous types and cultivars which differ greatly in composition and therefore in their suitability for certain culinary uses. Immature and mature fruits of *C. moschata* are used as a blanched, steamed or fried vegetable and as an ingredient of soups.

Various desserts are made from the fruits: steamed flesh with grated coconut and sugar, crisps made from steamed meshed flesh mixed with cassava flour, pumpkin custard, pumpkin pudding, pumpkin in coconut milk and sweet pumpkin paste. Ornamental gourds are cultivars of *C. pepo* with small, bitter and inedible fruits in many shapes, sizes and colours. The potential of the seeds as a source of vegetable fat and protein has not been fully exploited. Fresh seeds have been reported to be used as a vermifuge, and seed decoctions as diuretic and to reduce fevers. World production of pumpkin, squashes and gourds in 2003 was estimated at 17.4 million tonnes. The highest production was in Asia (10.6 million tonnes), with China being the major producer (4.2 million tonnes). Total production in Europe was about 2.1 million tonnes, with Ukraine, Italy and Spain being major producers. Africa produced 1.8, South America 0.7 and North and Central America 1.9 million tonnes, respectively (CABI, 2007).

2.1.4 Pumpkin production in Zambia

Relief

Zambia, a landlocked country sharing boundaries with Angola, Botswana, the Democratic Republic of Congo, Malawi, Mozambique, Namibia, Tanzania and Zimbabwe. It belongs to the Least Developing Countries (LDC) and has a total surface area of about 753 000 km^2 and lies between 8 ° and 18 ° south latitudes and longitudes 22 ° and 34 ° east.

The country lies on the great plateau of Central Africa. Relief consists of gently undulating to flat plateaux occasionally broken by hills and rocks. The country benefits from inter-regional transitions of the broad eco-zones of floristic diversity from the neighbouring centres of plant endemism. It is traversed and incised by numerous rivers including the Zambezi, Kafue, Luangwa and Chambeshi rivers forming varied topography from extensive valleys and wetlands through the grasslands and woodlands to the escarpments, all of which form various landscapes and habitats to a diverse range of plant genetic resources. Out of the recorded 5 500 flowering plants, 88 mosses and 146 ferns, cultivated plants constitute 2.3% of this diversity, which is dominantly in the hands of indigenous local communities and smallholder farmers (ZNTB, 2011).

Climate and agro-ecological zones

Based mainly on rainfall, temperature and relative humidity, three distinct seasons are experienced in Zambia as follows:

i. A cool dry season from April to August;

ii. A hot dry season from August to November; and

iii. A warm wet season from November to April.

During the cool dry season, mean night temperatures drop to between 7°C and 10°C particularly in June and July. The highest annual average temperature is 32°C and the lowest temperature averages 4°C. Table 1 presents annual rainfall and representative maximum and minimum temperature during the hottest and coldest months of the year respectively in some cities and towns in Zambia.

Annual temperature variation is greatest at Livingstone, the most southerly town and least at Mbala, the town nearest to the Equator. Mean relative humidity decreases steadily from April and reaches its minimum level in September. Temperatures rise rapidly from end of August signalling the arrival of the hot dry season, with maximum temperatures experienced in October.

From October, relative humidity begins to rise marking the onset of the rain season, and by the end of November, the warm wet season commences. Cloud cover and the falling rain lead to reduced temperatures despite the potential for heating. The rains gradually drizzle out by end of March in the Southern part of the country though they may continue until the beginning of April in the northern part of the country (ZNTB.

2011). Zambia's climate is favourable for agriculture with abundant arable land receiving mean annual rainfall of 650 mm in the southern part of the country and 1 800 mm in the north. The rainfall is unimodal and is influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ). The rainfall increases from an annual average of 600 mm in the lower south to 1 300 mm in the upper north of the country. Drought conditions have been on the increase during the last 30 years with the 1991/02 drought being the worst experienced so far.

The 1978/79 period saw the wettest conditions in Zambia. From 2000 to 2007, there have been two drought years, two flood years and two normal condition years. The intensity and frequency of droughts and floods has been increasing. The geographical distribution of these events have also been changing. These climatic variations have caused immense food shortages adversely affecting humans and wildlife as well as the economic infrastructure. The impact of the 2006/ 07 floods in all the affected areas was cross cutting affecting 1 443 583 people in 41 districts of the nine provinces of Zambia. These floods affected all sectors of the economy (ZNTB, 2011).

The rainfall patterns in Zambia according to agro-ecological zones are as follows:

Region I - includes the Zambezi, Gwembe, Luangwa and Lusemfwa Valleys, including the extreme southern ends of the Western and Southern Provinces with elevation ranging between 900 and 1200 m above sea level (asl). Mean annual rainfall in this region is low and does not exceed 800 mm. The harshest climatic conditions (climatic hazards) are observed in this region and thus Region I is considered a drought-prone/risk area;

Table 1: Average rainfall and temperature of some towns in Zambia

Station	Altitude (m)	Annual Rainfall (mm)	Maximum Temperature (^{o}C) October	Minimum Temperature (^{o}C) June
Mbala	1 633	1 140	28.2	10.6
Kasama	1 380	1 240	31.9	10.1
Mpika	1 393	1 110	30	10.1
Mansa	1 178	1 050	32.6	6.8
Mwinilunga	1 354	1 320	30.6	6.8
Ndola	1 262	1 150	32.3	6.2
Kabwe	1 200	900	32.1	9.9
Lusaka	1 272	800	31.6	10.1
Petauke	1 030	950	33.1	12.3
Chipata	1 024	1 000	32.6	12.3
Mongu	1 047	950	34.2	8.7
Livingstone	981	740	34.8	7.1

Source: ZNTB, (2011)

Region II - covers the central parts of the country and includes the Central, Lusaka, Eastern, and the northern parts of the Southern and Western Provinces with elevation ranging between 900 and 1 300 masl. This region receives medium annual rainfall of between 800 and 1 000 mm. It has a total area of 27.4 million hectares of which 87% [23.8 million hectares (ha)] could be used for agricultural purposes, but only 50% is actually accessible. The rest has been set aside for national parks, game management areas and forests;

Region III – comprises mainly the Northern, Luapula, Copperbelt and North-Western Provinces with elevation ranging from 1100 to 1700 masl. The mean annual rainfall exceeds 1 000 mm. It is the largest with an area of 40.6 million hectares with very little set aside for national parks, game management areas and forests. Only 52.7% of the land is suitable for cultivation due to the soils being highly leached.

Due to relatively high temperatures, the average annual potential evapo-transpiration in Zambia ranges from 1 394 mm to 1 892 mm while the country average is 1 574 mm. Potential evapo-transpiration is larger than precipitation in Zambia. This means that Zambia is in a hydrological condition of precipitation deficit that amounts from 100 mm to 1 100 mm per year. This situation has implications on water availability and management in Zambia, particularly in agro-ecological Regions I and II. The annual rainfall decreases from an average of 1 200 mm in the north to an average of 600 mm in the south (Muliokela, 1997). The smallholder horticulture sector in Zambia is relatively underdeveloped with few farmers specialising either in vegetable or fruit production. Pumpkins and other cucurbit species, such as cucumber (*C. sativus*) and melons (*C. melo*), are grown mainly for their fruits during the rainy season throughout the country. Usually they are intercropped with other field crops such as cereals and cassava (*Manihot esculenta* Crantz), although they are also commonly planted with other traditional vegetables on old cattle kraal sites, waste dumps or on ash sites where trees have been burned during land clearing (Migochi and Luchen, 1997).

Pumpkin production is mainly for home consumption with surplus taken to the market. Table 2 shows the percentage distribution of various crops grown in urban agriculture of Lusaka, Central and Copperbelt Provinces. Due to the sale of pumpkins on informal markets, data on the national production levels were not accessible. Plate 1 shows sale of pumpkins by the road side in Central Zambia.

Commercial farmers grow species such as gemsquash (*C. pepo*), cantaloupe (*Cucumis melo cantalupensis* L.) and courgettes (*C. pepo*) throughout the year. These are exported to Europe and South Africa. More than 85% of Zambia's farmers are smallholders with average holdings of 4 ha who are also engaged in contract farming with commercial farmers. Zambia's exports of baby vegetables to the United Kingdom (UK) totalled £7.4 million in 2005 (Tembo *et. al*., 2009).

Table 2: Percentage distribution of total urban crop output by location

Type of Crop	Location				Total
	Ndola	Kabwe	Lusaka	Kitwe	
Maize	34.6	50.7	52.2	29.6	39.5
Pumpkins	8.8	9.0	12.6	10.0	10.3
Beans	11.2	4.5	11.6	5.4	8.8
Onions	8.3	7.5	1.4	10.0	6.8
Rape	6.8	4.5	4.8	7.5	6.3
Tomatoes	6.8	3.0	1.4	7.1	5.0
Groundnuts	4.9	3.0	6.8	3.3	4.7
Sweetpotatoes	3.9	3.0	4.3	2.9	3.6
Chinese cabbage	3.9	4.5	0.5	5.4	3.5
Others	10.7	10.4	4.3	18.7	11.5
Total	100.0	100.0	100.0	100.0	100.0

Source: Hampwaye *et al.*, (2009)

Plate 1: Pumpkin on sale along Lusaka - Kabwe road

Indigenous crops such as pumpkins have high potential of income generation and enhancing food security for smallholder farming communities. As such, the Golden Valley Agriculture Trust (GART) in collaboration with Non-Governmental Organisations (NGOs) has been promoting the indigenous crops seed multiplication and distribution (Table 3) to the people living with Human Immune Virus/ Acquired Immune Deficiency Syndrome [HIV/ AIDS] (Simunji, 2010). Furthermore, the National Nutrition Policy (NNP), developed in 2006 under the Ministry of Health (MoH), recognizes the fact that food entitlement for most rural households is linked to agriculture. The policy states that production of minor staple food crops has been fluctuating and at a low level, leading to increased vulnerability to food insecurity, especially among the rural population. Policy measures indicated include the need to promote increased food diversification, production and consumption, and the utilization of all available food resources in order to alleviate food shortage and enhance nutrition status.

Table 3: Seed produced and distributed to beneficiaries (kg ha^{-1})

Crop	Cropping Season				
	2006	**2007**	**2008**	**2009**	**2010**
Sorghum (*Sorghum bicolor*)	42 000	-	-	2 000	20 000
Pig weed (*Amaranthus hybridus*)	300	500	750	830	800
Cleome sp	135	200	280	60	150
Pumpkins	37	250	40	200	150
Sweetpotato (*Ipomoea batatas*) vines	40 000	60 000	-	-	60 000
Cowpea (*Vigna unguiculata*)	2 420	1 500	1 500	450	4 000

Source: Simuji (2010)

Cucurbits production constraints

Various factors have been reported to affect cucurbits production in Zambia. These include but not limited to, unavailability of affordable improved seeds to small scale farmers; limited access to credit facilities for inputs, poor storage and transport infrastructure, poor marketing system and inadequate knowledge about pest management (Neguwo, 2004). Cucurbit production is also threatened by ravages of insect pests. Among them are fruit flies (Diptera, Tephritidae). White and Elson-Harris (1994), White, (2006) and CABI (2007) have listed most of the fruit flies of economic importance including those occurring in Zambia and the Afrotropical region.

2.2 Fruit flies attacking pumpkins

2.2.1 Description and distribution

Tephritidae are one of the most families of devastating crop pests occupying a prime position of quarantine pests in the world (Jayesankar, 2009). This family can be divided into two groups defined by their physiological and ecological characteristics.

The first group includes univoltine species that have diapause, located in temperate regions such as the genera *Rhagoletis*. The second group includes genera *Anastrepha* Schiner (New World Tropics), *Ceratitis* MacLeay, *Bactrocera* Macquart and *Dacus* Fabricius (Old World Tropics). These are multivoltine species distributed in tropical regions and do not undergo diapause during their life history. Ekesi (2010) reported that Sub-Saharan Africa is the aboriginal home to 915 fruit flies species from 148 genera, of which 299 species develop on wild or cultivated fruit or both. Highly damaging fruit flies in Africa 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.

Bactrocera cucurbitae (Coquillett)

The melon fly, *B. cucurbitae* has been reported to damage 125 host plants and is a major pest of cucurbitaceous fruits and vegetables including some solanaceous crops. Melon (*C. melo*), cantaloupe (*C. melo cantalupensis*), cucumber (*C. sativus*), pumpkin (*C. maxima*), squash (*C. pepo*) and eggplant (*Solanum melongena* L.) are among its preferred cultivated hosts (Christenson and Foote, 1960; Akter *et al.*, 2010; Khan *et al.*, 2011). This species is distributed in some parts of Africa, the Middle East, Southeast Asia, Micronesia and Hawaii with India considered as its native home. It has a pedicel with the first flagellomere not longer than ptilinal suture. The face has a dark spot in each antennal furrow with a round to elongate facial spot. The frons has 2 to 3 pairs of frontal setae and a pair of orbital setae (White, 2006).

Scutum is predominantly red to brown in colour. The postpronotal lobe is entirely pale yellow or orange. This species has a yellow notopleuron callus. Its scutum has parallel sided lateral post-sutural 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 anepisternal stripe does not reach the anterior notopleural seta. Both its anatergite and katatergite have yellow marking on them. The postpronotal lobe on this insect has no seta but the notopleuron has anterior seta. Besides the prescutellar acrostichal setae, the scutum may or may not have anterior supra-alar setae. The scutellum rarely has both the basal as well as an apical pair of setae (White, 2006).

The wing has a complete costal band stretching to below R_{2+3} and sometimes reaching R_{4+5}. The costal band expands into a spot at the wing apex which extends about half way towards M (Plate 2). It has an anal streak. Cells bc and c are colourless. There may be a transverse mark over crossvein r to m but it has always a transverse mark over cross-vein dm to cu. The cells bc and c are not extensively covered with microtrichia while cell br is extensively covered with microtrichia (White, 2006).

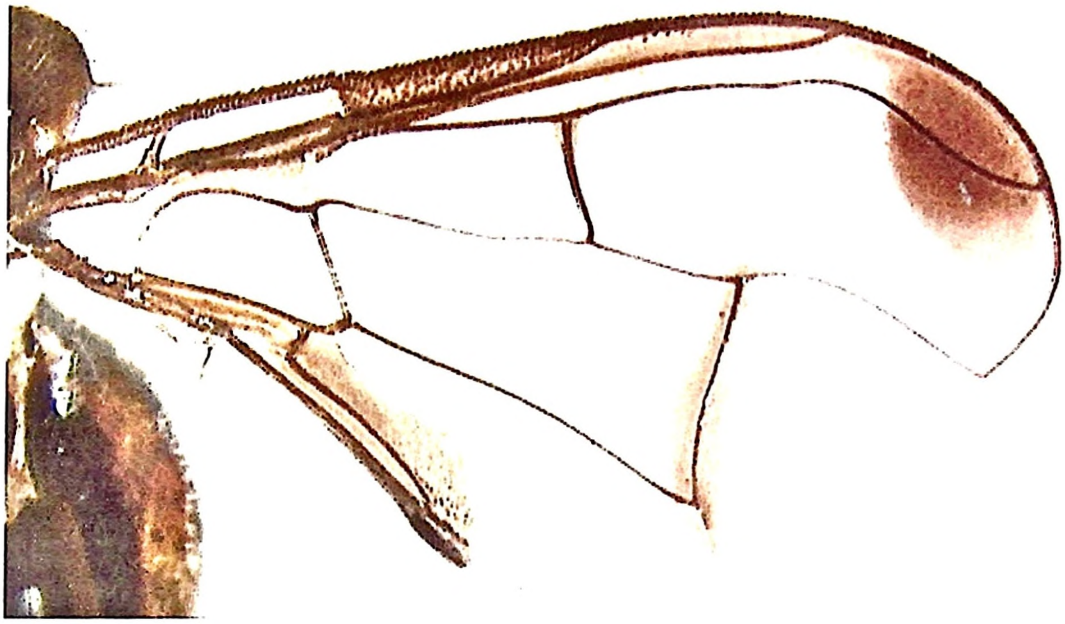


Plate 2: Wing venation of male *B. cucurbitae* Source: White (2006)

All femora are pale basally and apically red to brown in colour. The abdomen is predominantly orange to brown and not wasp waisted. Its tergites are not fused. The abdomen has a distinct pattern consisting of a transverse band across tergite 3 with tergite 4 dark laterally and medial longitudinal stripe on tergites 3 to 5. The wing of a male specimen has no bulla but has a deep indent in posterior margin. Its tergite 3 has a pecten on each side. Furthermore, the sternite 5 is not V-shaped while surstylus has a long posterior lobe. The hind tibia has a preapical pad. The aculeus apex is pointed (White, 2006).

Dacus ciliatus Loew

This species is usually referred to as the 'Ethiopian fruit fly' and has also been known as *Dacus brevistylus* Bezzi in the Indian subcontinent. Due to its preference for melons it is also called the 'Ethiopian melon fly'.

The normal hosts of *D. ciliatus* are all species of Cucurbitaceae. However, there are a few reports from other hosts including tomato (*Lycopersicon esculentum* Miller), beans (*Phaseolus vulgaris*), cotton (*Gossypium* sp.) and okra (*Abelmoschus esculentus*) (White and Elson-Harris, 1994).

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. The male has a pecten. Its scutum has no yellow stripes but the anterior supra-alar setae and prescutellar acrostichal setae are present (White and Elson-Harris, 1994).

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. White and Elson-Harris (1994) reported that *D. bivittatus* major cucurbit host range includes watermelon (*C. lunatus*), squash (*C. maxima*), cucumber (*C. sativus*), canterloupe (*C. melo cantalupensis*) while other hosts include but not limited to pumpkin (*C. pepo*), papaya (*Carica papaya*), tomato (*L. esculentum*) and coffee (*Coffee* sp.) (White and Elson-Harris, 1994).

The adult fly is predominantly dark orange to red-brown with facial spots. Its scutum has lateral and medial yellow stripes with an anterio supra-alar setae, 2 scutellar setae and no prescutellar acrostichal setae. The wing has a very broad coastal band from base to apex. The male specimen has a pecten. This species is known to occur throughout Africa and its males are attracted to cue lure (White and Elson-Harris, 1994).

***Dacus punctatifrons* Karsch**

In several African countries, Indian Ocean and Middle East, *D. punctatifrons* is widespread and has been recorded. It attacks a wide range of Cucurbitaceae but has also been reared from tomato and wild watermelon (*Passiflora foetida*) (White, 2006; Mwatawala *et al.*, 2006).

It is a predominantly orange-brown species with facial spots. Its scutum has a medial black stripe or predominatly black with lateral and medial yellow stripes. It has a pair of scutellar setae and an anterior supra-alar setae. 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).

***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).

2.2.2 Ecology and biology of fruit flies of cucurbits

Understanding of the biology and life history of phytophagous pests is a pre-requisite to appreciating their relationship to their host plant(s). The general biology of fruit flies has been reviewed by Christenson and Foote (1960) while Fletcher (1987) reviewed the biology specific to the sub-family Dacinae. Most known Dacines are multivoltine and have a similar life cycle (Plate 3). They locate the fruit they require for food and egg-laying by a series of visual, olfactory and tactile stimuli, the importance and sequence of which are peculiar to each species, and which also depend on climatic factors. Once a potentially suitable fruit has been located, the female explores it before attempting to oviposit. Many species, including *D. cucurbitae* oviposit in recent oviposition stings of other females or in breaks in the skin caused by other agents.

Female tephritids are characterized by a long, extensible ovipositor allowing them to pierce the fruit and deposit their eggs in its pulp. The eggs hatch after several days, depending on the temperature, and doubtless also upon the physiological stage of the host fruit. Issuing from the eggs are whitish larvae, apodal but able to hop, which pass through three larval stages before transforming into pupae in the soil. Lifespan is peculiar to each species, with the polyphagous and multivoltine species having greater longevity. The males are attracted to cure lure (White and Elson- Harris, 1994).

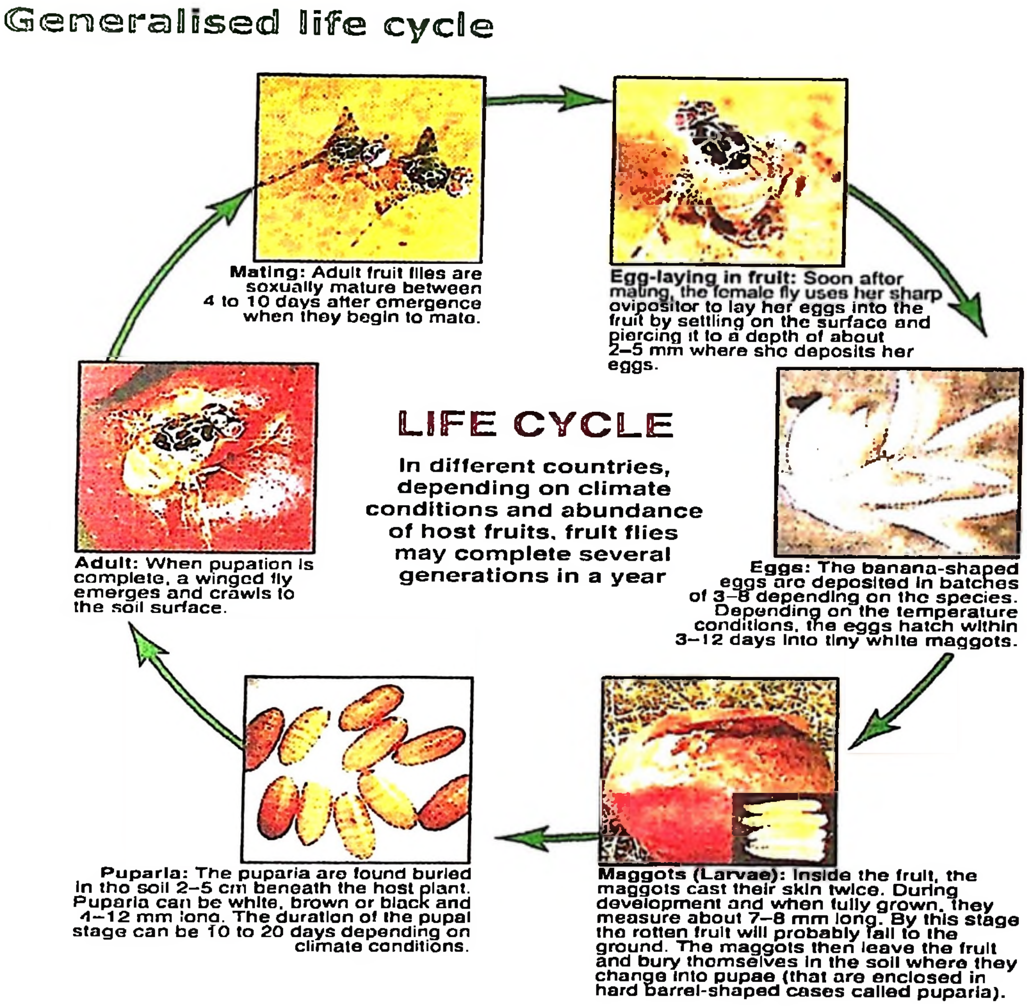


Plate 3: Generalised life cycle of tephritidae Source: Ekesi and Billah (2007)

With *B. cucurbitae*, eggs up to 40 clutch size, are laid 2 to 4 mm below the skin of the host fruit per oviposition. A female may lay more than 1 000 eggs. These hatch within 1 to 2 days and the larvae feed for another 4 to 17 days (longest in thick-skinned fruits such as pumpkin). The puncture left by ovipositing provides entry point for rot causing bacteria and fungi. Larvae pass through three instars before puparium formation. Pupariation occurs in the soil at 0.5 to 15 cm below the soil surface depending on the nature and type of soil (Dhillon *et al.*, 2005) under the host plant for 7 to 13 days but may be delayed for several weeks under cool conditions. After emergence, teneral adults feed for several days on sugars for survival and need protein from their habitat to attain sexual maturity (Fletcher, 1987). The lower developmental threshold for *B. cucurbitae* was recorded as 8.1°C (Keck, 1951). The lower and upper developmental thresholds for eggs were 11.4 and 36.4°C (Messenger and Flitters, 1958). The accumulative day degrees required for egg, larvae, and pre-egg laying adults were recorded as 21.2, 101.7, and 274.9 day degrees, respectively (Keck, 1951). This species actively breeds when the temperature falls below 32.2° C and the relative humidity ranges between 60 to 70%.

Adults occur throughout the year and begin mating at dusk under low light intensity (less than 1 000 lux) after about 10 to 12 days from emergence. Field cage studies indicate that males of *B. cucurbitae* engage in lekking behaviour (Kuba and Koyama, 1985). As light intensity drops near dusk, they aggregate on specific parts of a tree and take up individual territories on leaves, which they aggressively defend from incursions by other males. The males of the *B. cucurbitae* mate with females for 10 or more hours after which females become sexually unreceptive and sperm transfer increases with the increase in copulation time. However, egg hatchability is not influenced by mating duration (Tsubaki and Sokei, 1988). Males are attracted to cue lure.

Patel and Patel (1998) reared *D. ciliatus* in the laboratory (in *Coccinia grandis*) and noted that larval development took 4-7 days, pupariation 7-14 days, and adult longevity was 13-27, depending on the season. El Nahal *et al.* (1971) reported similar results from *C. pepo*, except that they reported pupariation times of up to 40 days. The final instar larvae of *Dacus* sp. drop to the ground, find a crack to go into, and then form a puparium within which pupation takes place. Males are not attracted cure lure, methyl eugenol or vert lure (White and Elson- Harris, 1994).

According to Christenson and Foote (1960), the eggs of *Dacus cucumis* (French) are laid beneath the host skin. The larvae mature in about a week and then crawl into the soil to pupariate. The whole life cycle can be completed in 2 weeks so populations can increase very rapidly. Borah and Dutta (1996) in their study on the biology of *Dacus tau* Walker on cucurbitaceous vegetables reported variation in parameters between hosts. For example, 10 larvae in *Momodica charantia* to 40 in *Lagenaria siceraria*. In *Trichosanthes cucumerina* development was completed in 11 days with other hosts taking up to 16 days. Furthermore Kabir *et al.* (1997) in their study on the biology, of *D. tau* noted that mating took place throughout the night with eggs being laid between 11 00 and 15 00 hours. Incubation period lasted for 1 to 3 days while adult longevity was up to 121 days for males and 191 for females.

2.2.3 Abundance and population dynamics of fruit flies of cucurbits

The annual population fluctuation of *B. cucurbitae* is determined using traps baited with cue-lure and insecticide in the target area. Cue lure has been reported to attract *B. cucurbitae* males more effectively than food lure (Zaman, 1995).

Laskar and Chatterjee (2010) used cue lure to investigate the influence of abiotic factors such as temperature, humidity and rainfall to investigate population fluctuation of *B. cucurbitae* in order to formulate a sustainable management technique against the pest in India. They found that during warm and rainy months (June, July, August, at 25 to 37°C) the flies were more active as compared to that of dry and winter (December, January, February 8 to 23°C) 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. Rainfall and sunshine hour per day showed positive and negative correlation with the fly incidence respectively. Kumar *et al.* (2006) determined the relative incidence of *B. 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 *B. cucurbitae* throughout the study period. Peak catches of *B. 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 *B. cucurbitae* showed a significant positive correlation with mean weekly relative humidity. Hasyim *et al.* (2008) assessed the seasonal fluctuation of male *B. tau* in passion fruit (*Passiflora edulis* Sims) orchards in Alahan Panjang, West Sumatra, Indonesia.

The correlation analysis of weather factors and fruit fly trapping showed that all abiotic factors (rainfall, rainy days and temperatures) correlated significantly with the number of fruit flies trapped with cue lure. Chen and Yen (2007) also in their work monitored the population dynamics of Oriental fruit fly, *Bactrocera dorsalis* Hendel.

year-round using methyl eugenol baited traps in 2003, 2004, 2005 and 2006 in Baoshanba, Yunnan Province, China. It was observed that this species occurred only during April to November, with one yearly peak in August. The population fluctuation patterns with respect to season were identical in all study years. Natural enemies have been shown to play a key role in the population dynamics of some tephritid species. For example generalist predators such as ants would affect more or less equally different tephritid species in a given biotope. Among natural enemies, parasitoids are generally more specific and could affect differentially the tephritid species coexisting in a given biotope. However, in most instances their impact on tephritid populations appears rather limited, with the exception of a few ovo-pupal species (Vargas *et al.*, 1993).

2.2.4 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 (White and Elson-Harris, 1994). 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 flies infestation causes economic damage (Clarke *et al.*, 2005; Follet and Neven, 2006).

According to examples given by Thompson (1996), if fruit flies were not controlled in Australia, it was believed that the potential losses would exceed A$100 million with an annual fruit production running over A$850 million. If a certain fruit fly species invaded California, crop losses could be in the tune of US$9 million. The eradication of the Oriental fruit fly (*B. dorsalis*) from the south-western islands of Japan using the Sterile Male Technique (SIT) costed approximately US$32 million and 200 000 man days (White and Elson- Harris, 1994) while annual losses in the eastern Mediterranean (Israel, Palestinian Territories, Jordan) linked to fruit fly infestations are estimated at US $192 million (Enkerlin and Mumford, 1997). One of the several cucurbit fruit flies that, if uncontrolled, causes considerable loss of yield is *D. ciliatus*. Hence, it poses a phytosanitary risk to other countries with a suitable tropical climate and suitable cucurbit crops. In Mauritius, Reunion and Madagascar, *D. ciliatus* was considered an exotic species. It has never been recorded in Seychelles and Comoros and is considered a Moderate risk pest for these countries due to its serious pest status in Reunion and Mauritius (Joomaye and Price, 1999).

Pradhan (1976) reported 28.7 to 59.2, 24.7 to 40.0, 27.3 to 49.3, 19.4 to 22.1, and 0 to 26.2% yield losses in pumpkin, bitter gourd, bottle gourd (*L. siceraria*) , cucumber, and sponge gourd, respectively, caused by *B. cucurbitae* from the field experiments on assessment of losses caused by cucurbit fruit fly conducted in Nepal. Considering previous facts and reports, Dhillon *et al.* (2005) noted that the extent of loss varies between 30% and 100%, depending on the cucurbit species and environmental conditions in different parts of the world. For example, 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. The Republic of South Africa prohibited the importation of cucurbits such as butternuts and melons from Botswana on the basis of suspected *B. cucurbitae* presence which was later found to be an incorrect identification (Gebeyehu, personnal communication, 2010).

Apart from economic losses, there may also be environmental costs as insecticide usage is increased in order to control the newly introduced pest. Moreover, repeated use of insecticides creates a hazardous situation for the environment as well as health of the farmers and consumers (Wasim *et al.*, 2010). Furthermore, the effect of ingested larvae on human health is an aspect of fruit fly problem which has received little studies. The only information available refers to *Anastrepha* sp. larvae causing abdominal pain and diarrhoea especially in children as reported by Jiron and Zeldon (1979) in White and Elson- Harris, (1994). Other species in the subfamily Tephritinae are important to world agriculture, not as pests, but as biological control agents that limit particular noxious weeds. For example, *Dacus* (*Leptoxyda*) *persicus* Hendel is the only dacine fruit fly that is a biocontrol agent. It attacks only ak plant or sodom apple, *Calotropis procera* (Ait.), which is of African origin. The distribution of this fly is closely associated with its host plant. The larvae of this fruit fly bore inside the host pods and destroy their content (White and Elson-Harris, 1994).

2.3 Management of fruit flies

Plant protection personnel are regularly faced with the problem of having to develop strategies for control of a pest species in a crop, often urgently. Pressure comes from various sources. Farmers who may be losing significant quantities of crop and earnings, and exporters who may be losing national and overseas markets, apply pressure in many different ways. Governments react to this pressure, and, for expediency's sake and to reduce the pressure applied by the farmers or exporters, a control strategy is promptly developed.

Historically and viewed from a world-wide perspective, fruit fly management and control has been basically depending on various techniques applied singly or in combination (Aluja, 1996). Various techniques for pest management have been reported by White and Elson- Harris, (1994). However, Aluja (1996) states that fruit fly management is in a transition period through which conventional methods are being substituted by more bio-rational techniques. These include perimeter trapping, insect growth regulators, sterile insect technique, habitat manipulation and parasitoid augmentive release. In the recent past decades, pest management relied exclusively on the use of agricultural chemicals. In many cases, no conscious effort was made to understand the pest in its environment as part of developing pest management strategies (Van Mele *et al.*, 2007). Though the approach of developing a short term solution based on insecticides may have been acceptable 20 years ago, it is no longer acceptable.

The negative aspects of chemical control are better known such as environmental contamination, residue problems, the killing of non-target organisms, and include the development of resistance to pesticides. The increasing cost of pesticides has become unaffordable to small scale farmers. Consequently, a more integrated approach to pest control was advocated. Many countries are promoting sustainable agricultural practice to promote and conserve biodiversity and to reduce the environmental impact of the intervention (Aluja, 1996).

According to Food and Agriculture Organisation (FAO) panel of experts, integrated pest management is a pest management system that, in the context of the associated environment and population dynamics of the pest species, utilizes all suitable techniques and methods in as a compatible manner as possible and maintains the pest population at a level below those causing economically unacceptable damage or loss (CABI, 2007). Consideration is given to social acceptability, ecological stability, environmental safety, and human resource development. Therefore, this study on understanding the diversity and population dynamics of cucurbits infesters in central Zambia will contribute to the development of an integrated pest management package for fruit flies to be managed more effectively and with fewer adverse effects on the consumers and the environment. Furthermore, consignments of fruits from countries where fruit flies of quarantine importance are known to occur should be inspected for symptoms of infestation by Plant Inspectors at entry points and those suspected should be cut open in order to look for larvae. Fruits may also be required to be treated in transit by cold treatment (e.g. 13 or 14 days at 0.0 or 0.6°C, respectively).

2.4 Climatic modeling

It is well recognized that threats by invasive pests to plants, whether crops, horticultural commodities, or members of natural communities such as forests and grasslands, are increasing as a result of globalization, increased human mobility, climate change, and pest evolution (Myerson and Reaser, 2002). The development of risk maps which describe the potential distribution and probability of establishment of a plant pest are likely to be useful to biosecurity agencies worldwide as they could assist in the development of strategies to mitigate the impact of the pest (Ganley *et al.*, 2009). Baker (2002) reviewed the data required and the techniques that can be used both for assessing establishment potential and for predicting the limits to the distribution of plant pests of quarantine importance once established in a country. Essentially, ecological factors (such as the suitability of the ecological environment, presence of hosts and natural enemies) and factors intrinsic to the pest itself (such as its reproductive strategy and genetic adaptability) should be considered when analysing the establishment potential of a plant pest.

MacArthur and Wilson (1967) introduced a classical dichotomy between the so called "r" and "k"-selected species. In their view, r-selected species display a suite of traits that favour rapid population growth and colonisation of new habitats, while k-selected species are adapted to competition in saturated habitats.

Although later studies have shown that the conditions of selection for "r" vs. "k" traits are much more complex than just density-independent vs. density-dependent population regulation (Reznick *et al.*, 2002), species often fall into "r" or "k" syndromes. Some species tend to mature early, have small size, high growth rates, little resistance to competitors, and efficient dispersal; while others present long lifespan, low fecundity, large sizes, and little mobility. However, in the case of invasion in the presence of resident competitors, invasion may ultimately depend on the ability to outcompete, or at least to resist competition exerted by, resident species. . For example, *Ceratitis capitata* (Wiedemann) was once invasive in the presence of *Ceratitis catoirii* alone, but is no longer invasive in La Réunion since the better competitors *Bactrocera zonata* (Saunders) and *Ceratitis rosa* (Karsch) arrived (Duyck *et al.*, 2007).

Headrick and Goeden (1998) affirms that climate based bio-geographical analysis can indicate the likely future range and outbreak areas of pests, vectors and natural enemies. Based on its influence on pest population dynamics and species competition, climate is a critical component for the geographic assessment of potential pest distribution. For example, Duyck *et al.* (2004) studied the influence of temperature on *B. zonata* in order to better understand the potential limits of the distribution of this species on Réunion Island and in other countries and for a comparison of its biological characteristics with those of related species. The results of this study indicated that the northern or southern latitudinal limits of *B. zonata* should not be as high as those of *C. capitata*. In lowlands areas where temperatures are highest, *C. capitata* dominates tallying with the minimum developmental threshold for the species.

Tsitsipis and Abatzis (1980) observed that in *Bactrocera oleae* (Gmelin), the egg development time at 20°C could increase from 84 to 102 hours if relative humidity decreased from 100 to 75%. However, in the wild, the effect of humidity on the embryo stage and larval instars is undoubtedly modulated more by the host fruit than by the climatic conditions.

A number of climate-based risk mapping systems, such as CLIMEX©, BIOCLIM©, and GARP©, have been used for pest risk analysis (Edith and Graham, 2006). De Meyer *et al.*, (2010) used two correlative ecological niche modeling techniques (GARP© and a Maximum Entropy method) to estimate the potential distribution of *B. invadens*. Their models indicated regions of the world that are climatically suitable for the species, but they do not indicate regions that will necessarily become invaded by the species. Introduction into the area alone is insufficient to ensure that the species will establish. For a species to become established in a new region, it has to overcome a number of barriers (De Meyer *et al.*, 2008).

Stephens *et al.* (2007) in their bio-climatic modeling work used CLIMEX modeling to infer the response of *B. dorsalis* to climate and predict its potential to colonise new areas. The projected potential distribution included much of the tropics and subtropics and extended into warm temperate areas such as southern Mediterranean Europe with cold stress limiting the distribution. Similarly, Yonow and Sutherst (1998) used CLIMEX modeling to analyse the potential distribution of *Bactrocera tryoni* (Froggatt) in order to understand the limiting effects of climate on the geographical distribution of *B. tryoni* in Australia. The analysis indicated that the eastern areas of Australia were most suitable for the pest with suitability declining towards the south. By assessing the likely climatic suitability of plant pests, individual biosecurity agencies can decide whether to devote scarce resources toward detecting or preventing its entry. Similarly, they can consider likely entry pathways via climatically suitable routes, with a view to attenuating the flow of propagules if necessary. The bio-climatic modeling (BIOCLIM©) can support pest risk analysis and management decisions by providing the best estimates as to whether a pest can occur in a given place. If an area may be vulnerable to infestation, resistant or tolerant crops can be grown, or an early detection system can be put in place to prevent the introduction and spread of the pest. However, if the risk of a pest being introduced in an area is negligible, Phytosanitary measures could not be required. Nonetheless, Baker *et al.* (2005) cautioned that while climatic comparisons are useful, care must always be exercised since many other factors influence distribution. Even where climate is known to be important. the climatic factors selected and the methods used for their measurement and analysis need to be relevant to the species concerned.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

Zambia is a landlocked nation located in Central Africa. It is bordered by Angola in the west; Namibia, Zimbabwe, Mozambique and Botswana in the south; Tanzania in the northeast; and Congo in the north. It is the world's 39th largest country with an area of 753 000 km^2 approximately. Zambia is a nation that experiences a tropical climate controlled by the Inter-Tropical Convergence Zone (ITCZ). Distribution of fruit flies in Zambia was studied by sampling adults from several districts along major highways in the country. Fruit fly presence or absence data was recorded using Cue lure. Population dynamics were studied at three sites representing the three agro-ecological zones of Zambia. The first site is Mufulira located on the Copperbelt Province of Zambia (Longitude 28°09'27.5718"E, Latitude 12°37'54.5406S", Altitude 1 205m) representing Region III. Lusaka is the second site (Longitude 28°15'6.1488"E, Latitude 15°33'1.3932"S, Altitude 1 193m) representing Region IIa and the last site is Monze (Longitude 27°26'28.3884"E, 16°14'21.0546"S, Altitude 1 110m) representing Region IIb. While infestation rate, fruit flies species composition and diversity studies were conducted in Chilanga, Chisamba and Kabwe sites.

3.2 Land preparation and crop management

The field was disc ploughed and harrowed to a good tilth in November, 2010. An experimental plot measuring 7m wide and 7m long was prepared. Soil samples were taken using a hand trowel at a depth of 30cm in November, 2010.

Compound "D" was applied as basal dressing at a rate of 400kg ha^{-1} and Ammonium nitrate was applied for top dressing at a rate of 100kg ha^{-1} in a split application based on the recommendation from Zambia Agriculture Research Institute (ZARI), Soil Chemistry laboratory. Pumpkin local cultivar was planted at a depth of 2 to 5 cm with a seed rate of 5 kg. No pesticides were used during the crop growth and development. Weeding was mechanically done using a hand hoe.

3.3 Insect sampling technique

Insects were collected using two main methods trapping and fruit collection for rearing the flies. Traps were baited with an attractant in combination with an insecticide. The insecticide was placed in each trap to kill attracted and trapped adult male fruit flies Traps were suspended in a fruit tree or on poles at the study site at a height of approximately 2m from the ground. This created a continued surge to attract male fruit flies. Traps were inspected on monthly basis and fruit flies caught per trap were collected using a brush and placed into vials containing alcohol (70%) for preservation, labeled and transported to the laboratory at Mount Makulu Central Research Station in Lusaka for species identification and counting. Details of the location were taken.

Furthermore, fruits were harvested two months after planting and placed in a plastic bag before putting them in a 6 - litre container. The top of the plastic bag was pulled over the rim of the container to lift the fruits off the bottom of the container. Elevating the fruits above the bottom of the container reduces physical damage to the fruits due to bumpy roads. To ensure circulation of air, the inner part of the lid of the container was cut out and replaced with a tight weave synthetic mesh capable of retaining emerged insects during transportation. Harvested fruits were cleaned, weighed and counted (Copeland *et al.*, 2002).

The cleaned and weighed samples were placed in well labelled rearing cages and kept under observation for the emergence of adult fruit flies. Fruits were bulked in each rearing cage. The rearing cages were made of transluscent 6 - litre plastic bowls (Plate 4). A big area of the central part of the lid of the bowl was cut and removed from the lid. A net was fitted to the lid in order to provide for ventilation. The bowl was filled with 4 kg of heat sterilised sand to allow for pupariation of third instar larvae of fruit flies. The bottom of the bowl was perforated to provide for drainage of water coming from rotting fruits.

3.4 Determination of species composition and diversity of cucurbits infesters in Central Zambia

The study on determination of species composition and diversity of cucurbit infesters was undertaken during the 2010/ 11 cropping season of Zambia. A Completely Randomised Design (CRD) was used to determine the species composition and diversity of cucurbit infesters in Central Zambia with location as a source of variation. The experiment was replicated three times in time during the cropping season. The experimental sites were Kabwe, Chilanga (Lusaka) and Chisamba. Central Zambia was chosen due to its high potential of both domestic and export markets for pumpkins and other cucurbits. The experiment involved short time exposure trapping (48 hours) using Chempac bucket traps baited with Cue lure (CL) [4-(phydroxyphenyl)- 2-butanone acetate] and 2,2 dichlorovinyl dimethyl-phosphate (DVDP) strips as describe in Section 3.3. Sampling of pumpkin fruits from the mentioned three sites was also done.

A $1m^2$ wooden quadrant was used to sample fruits by throwing it once in the plot and fruits from the quadrant were harvested. Fruits harvesting was done from the plot at two months after date of planting. Rearing of fruits (Plate 4) was done following the procedure described in Section 3.3. Samples were cultured for fruit-fly emergence up to four weeks, after which they were discarded if no further adults emerged. Emerged adults were fed on sugar solution for four days in order to allow them develop full body coloration and normal shape. Then they were chilled to death before being collected, identified, counted and preserved in 70% ethanol.

The identification of flies was done using standard keys and characters described by Ekesi and Billah (2007), White and Elson-Harris (1994), White (2006) and CABI (CABI, 2007). Specimens which could only be identified up to the genus level were sent to South Africa – University of Pretoria (UP) for species identification. Data collected included name of site, geographical location, date, number of pumpkin fruits, name of fruit fly species and number of fruit flies per species.

Plate 4: Rearing cages for pupariation

3.5 Determination infestation rate of cucurbit infesters on pumpkin in Central Zambia

To determine infestation rate of cucurbit infesters on pumpkin in Central Zambia, a survey was conducted during the 2010/11 cropping season. The survey was conducted in February, 2011 two months after the official announcement of the planting time by the Meteorological Department. It involved random sampling of pumpkin fruits from different locations in Central Zambia following the Great North road from Lusaka to Kapiri Mposhi (T3 road). Fruit sampling was done with the help of extension staff. The data on fruit fly infestation were collected by counting sampled infested fruits. Infested fruits were identified by having a puncture mark made by the entry of the female's ovipositor or having some sign of decayed tissue around the "stings" (Plate 5). Rearing of fruits was done following the procedure described in Section 3.3.

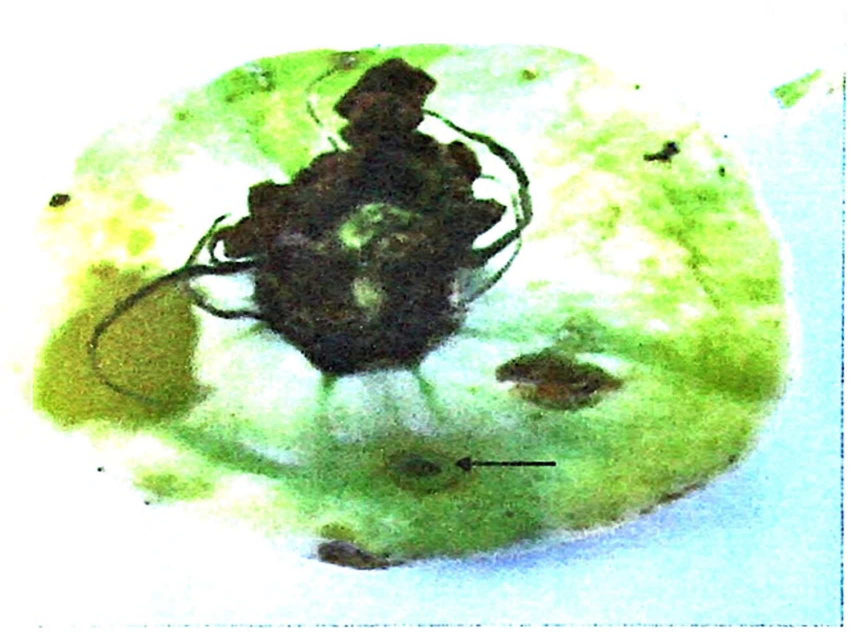


Plate 5: Puncture mark on an infested pumpkin fruit

Infestation indices were determined as number of emerged fruit fly adults of a fruit fly species per number of fruits and the number of emerged fruit fly adults per kg of fruits.

3.6 Assessment of distribution and seasonal abundance of fruit flies in Zambia

To assess the distribution of cucurbit infesters in Zambia, Chempac bucket traps (Plate 6) baited with CL in combination with DVDP were used following the trapping procedure described in Section 3.3. CL, a male specific attractant was used in order to attract members of the *Dacus* spp. and *B. cucurbitae*. Traps were randomly placed at selected districts along main trunk roads with an exposure period of 48 hours.

In the southern region of the country, the Walvis Bay Corridor linking Zambia to Namibia was followed from Lusaka to Sesheke via Livingstone (T1and M10 roads). For the western region, the Great West Road (M10 road) from Lusaka to Senanga via

Mongu was followed. The North-Western region was covered following the KapiriMposhi – Solwezi route (T3 road). The Northern Region was covered using the Tazara Corridor up to Nakonde (T2 road). A detour was also followed from Mpika to Mpulungu via Kasama (M1 road).

Fruit flies caught per trap were collected and placed into vials containing 70% alcohol for preservation, labeled and transported to the laboratory at Mount Makulu Research Station for species identification and counting (Plate 7) using standard keys and characters described by Ekesi and Billah (2007), White and Elson-Harris (1994), White (2006) and CABI (2007). The data collected included name of province, district, site, species name and geographical location.

In order to assess seasonal abundance of fruit flies in Zambia, Chempack traps were used in a CRD experimental design, with season as a source of variation. The experiment was replicated three times. Three trapping sites were selected in each agro-ecological zone of Zambia. Trapping procedure described in section 3.3 was followed. Fruit fly abundance data by species was collected monthly. Traps were recharged with CL and DVDP on monthly basis.

Plate 6: Hanged chempac bucket trap baited with Cue lure and dichlorovos at Monze

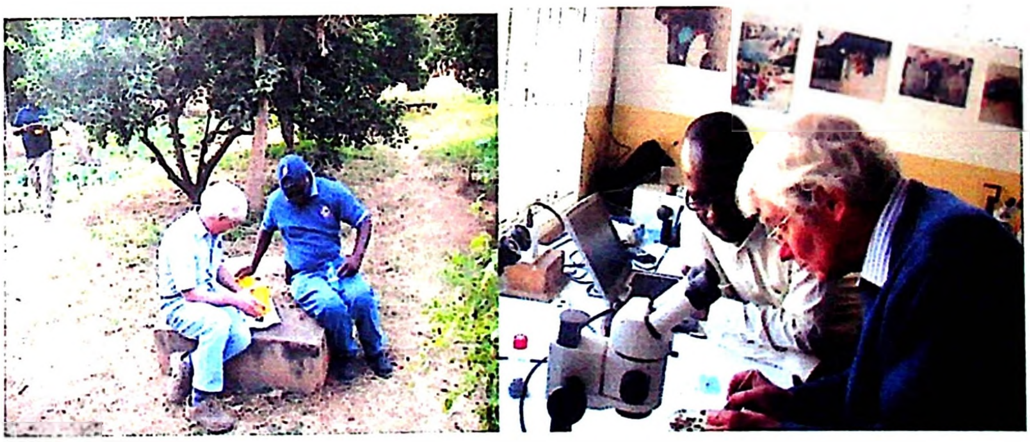


Plate 7: Fruit flies sample collection and laboratory identification

3.7 Determination of influence of climatic factors on fruit flies abundance

In order to determine whether there was a correlation between climatic factors and fruit fly abundance, monthly mean temperature (°C minimum and maximum), relative humidity (%) and rainfall (mm) was collected from the nearest weather station to the sampling site. The climatic data was then correlated with fruit fly abundance data collected in Section 3.6.

3.8 Development of a model to predict potential distribution of fruit flies in Zambia

CLIMEX (Version 3), a computer modelling software was used to predict the potential distribution of cucurbit infesters in Zambia. It uses long term average meteorological data to derive weekly and annual population growth indices (GI) which describe the potential of the location concerned to support population growth of a nominated species during the favourable season.

Annual stress indices (cold, hot, dry and wet) and stress interaction indices (hot-wet, hot-dry, cold-wet and cold-dry) describe the severity of the unfavourable season in terms of the probabilities of extinction of the population. These indices are then combined into an annual ecoclimatic index (EI) which describes the potential for the persistence and growth of the population.

The meteorological data [Monthly averages of daily precipitation, daily temperature (°C, minimum and maximum), relative humidity (%)] available for use within CLIMEX, as a 0.5 degree of arc dataset, generated from climate normals over a thirty year period were used to predict the potential distribution of *B. cucurbitae* in Zambia. The Melon fly is an invasive pest of quarantine importance reported in the region (Ekesi and Billah, 2007; Mwatawala *et al.*, 2010).

The Compare Location function for one species was used to predict the potential geographical distribution of *B. cucurbitae* in relation to climate only based on its climatic preferences. The set of locations to which the simulation was to be run was specified under Zambia.

The *B. cucurbitae* file was created in CLIMEX by copying the parameters of *Ceratitis capitata* using the Species button (**Add/Edit/Remove**). The *C. capitata* model was picked on due to closer relationship with *B. cucurbitae*. The CLIMEX parameter values for *B. cucurbitae* were defined using the known biological data and distribution (Dhillon *et al.*, 2005). The values were iteratively adjusted using the Parameter button (**P**) until there was a close visual match between the endemic and predicted distribution. The effect of climate change due to the enhanced greenhouse effect was not investigated. The model was validated using the known native and invaded places in Asia and Africa.

3.9 Data analysis

In order to determine whether study sites in Central Zambia were different in their fruit flies species composition and diversity, Ochiai, Dice and Jaccard's Indices were applied using PAST version 2.11 (Paleontological Statistics software package for education and data analysis). The closer the index is to 1 or 100%, the similar the sites and vice versa

One way analysis of variance (ANOVA) followed by means separation [Least Significant Difference (LSD)] using STATISTIX © (Analytical Software, 2003) was used to determine if there are significant differences in fruit fly abundance between agro-ecological regions and as well as seasons.

To identify the distribution pattern of fruit flies in Zambia, the sample variance (S^2) of fruit fly data collected from the districts sampled along the major trunk roads in Zambia was compared to its arithmetic mean ($\overline{X}$). The sample variance was calculated using the following formula:

$$s^2 = \frac{\Sigma\chi2 - [(\Sigma\chi)\ 2/n]}{n-1} \qquad \text{..1}$$

Where;

$\sum$ denotes summation

x = the number of fruit flies species per site

n = total number of samples (trapping sites)

The arithmetic mean ($\overline{X}$) was calculated using the formula:

$$\overline{X} = \sum x / n$$

where the symbols are as shown above for the sample variance. The departure of the coefficient of distribution (S^2 / mean) from Poisson randomness was tested by calculating the distribution index (ID) given by the following expression:

$$ID = \frac{s^2\ (n-1)}{m} \qquad \text{...2}$$

Where;

n = number of fruit flies trapping sites

m = the arithmetic mean number of fruitflies

The ID value was then compared with the Chi-square value at n-1 degrees of freedom. Where the ID value is more than the Chi-Square value, it means the distribution deviates from a random Poisson one. Where the ID value is less than the Chi-Square value, then the distribution approximates a random Poisson distribution. A multiple regression analysis using linear regression modeling was performed using PAST Version 2.11 between the mean monthly trap captures in the three districts and the monthly data for the recorded climatic factors in order to determine the correlation between climatic factors and fruit fly abundance. Recorded climatic factors included rainfall (mm), relative humidity (%), minimum and maximum temperature (^{o}C). The correlation coefficients were used in the identification of climatic factors with the greatest influence on fruit fly abundance. Regression analysis was used to derive linear equation models that can be used to predict fruit fly abundance from climatic data.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Species composition of fruit flies attacking cucurbits in Central Zambia

A total of 11 fruit fly species belonging to the family Tephritidae were identified from trapping and fruit rearing experiments. A total of 2 439 specimens were collected during the study (Table 4). The species belong to two genera namely *Dacus* and *Ceratitis*. Nine species representing 81.8% of the species composition belong to the genus *Dacus* while the other two species representing 18.2% belong to the genus *Ceratitis.* Chilanga had nine species while Chisamba and Kabwe had four and seven species respectively. The three most frequent species encountered and were detected in all the three sites were *D. bivittatus*, *D. ciliatus* and *D. vertebratus*.

The less frequently encountered species in the study area included *Dacus kariba* Hancock, *Dacus eminus* Munro, *Dacus africanus* Adams, *Dacus chiwira* Hancock, *D. punctatifrons*, *Ceratitis cosyra* (Walker) and *Ceratitis fasciventris* (Bezzi). They were either found in one site or represented by a single specimen as was the case with *D. africanus* and *C. fasciventris*.

Specimens of the following species were only obtained from the trapping experiment: *D. africanus*, *D. kariba*, *D. chiwira*, *D. eminus*, *D. venetatus* and *C. cosyra*. The species which were collected from both trapping and rearing experiments included *D. vertebratus*, *D. punctatifrons*, *D. bivittatus* and *D. ciliatus* while the species recorded from fruits only was *C. fasventris*.

Table 4: List and number of fruit flies recorded per site from Central Zambia

Species	Site			Percentage of total specimens (%)
	Chilanga	Chisamba	Kabwe	
Dacus bivittatus	441	244	175	35.2
Dacus punctatifrons	15	-	1	0.7
Dacus ciliatus	507	10	70	24.1
Dacus venetatus	1	5	3	0.4
Dacus eminus	15	-	-	0.6
Dacus chiwira	14	-	7	0.9
Dacus kariba	3	-	-	0.1
Dacus africanus	-	-	1	-
Dacus vertebratus	179	272	353	33.0
Ceratitis cosyra	-	-	4	0.2
Cerartitis faciventris	1	-	-	-
Others	76	20	22	4.8
Specimens Total	**1 252**	**551**	**636**	**100**

Similarity in species composition

Between sites diversity was determined using three different indices. The Dice index of similarity revealed a relatively higher similarity (0.74) between Chilanga and Kabwe while the similarity between Chisamba with either Chilanga or Kabwe was 0.70 (Fig. 1). The Ochiai's index of similarity showed an index value of 0.74 for the similarity between Kabwe and Chilanga. The similarity between Chisamba and either of the other two sites was 0.73 (Fig. 2). The Jaccard's index showed the lowest value of 0.58 for the similarity between Chilanga and Kabwe while the index value between Chisamba and the other sites was 0.52 (Fig. 3).

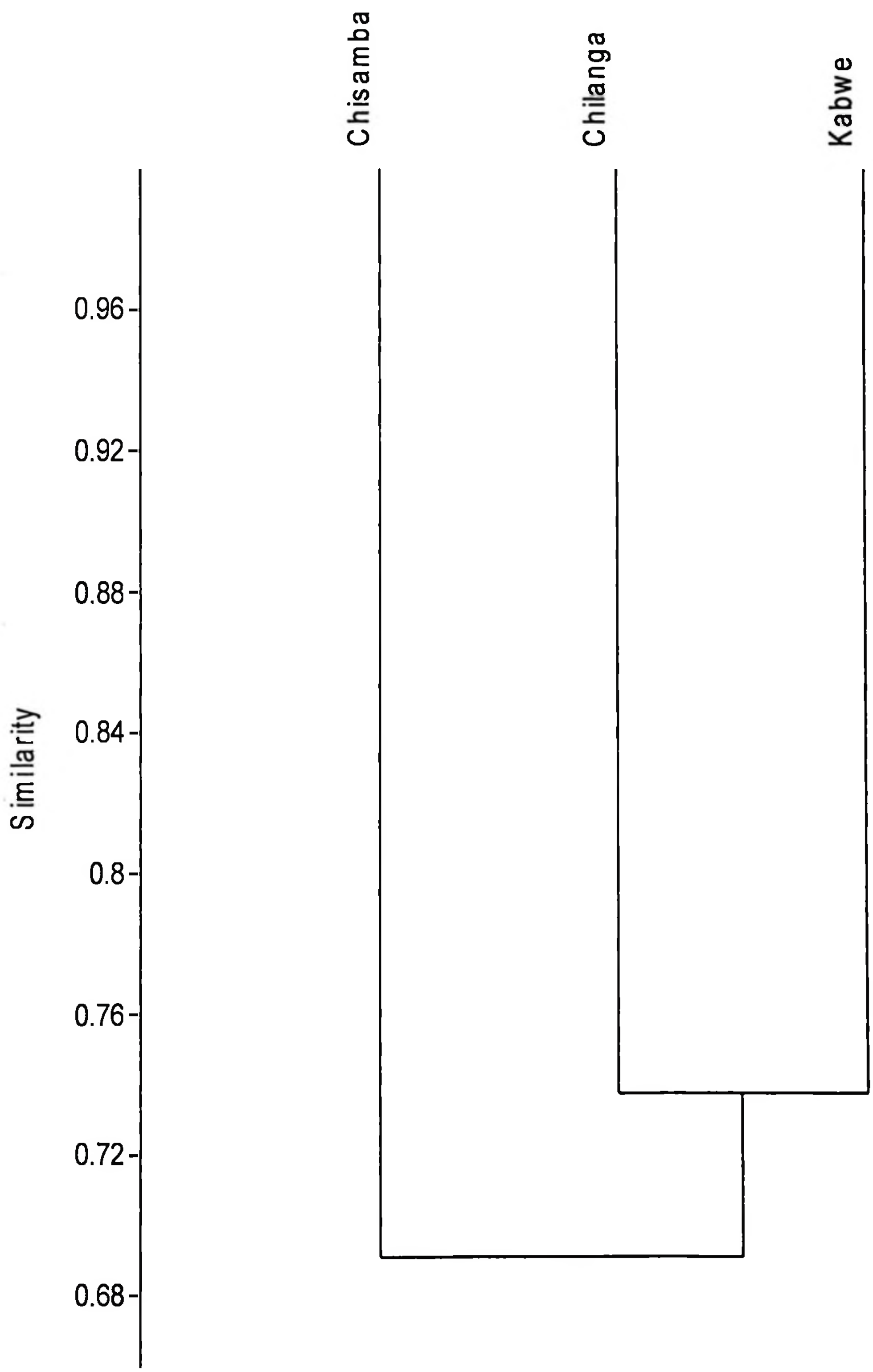


Figure 1: Dendrogram showing constrained Dice's index of similarity among the three study sites in Central Zambia.

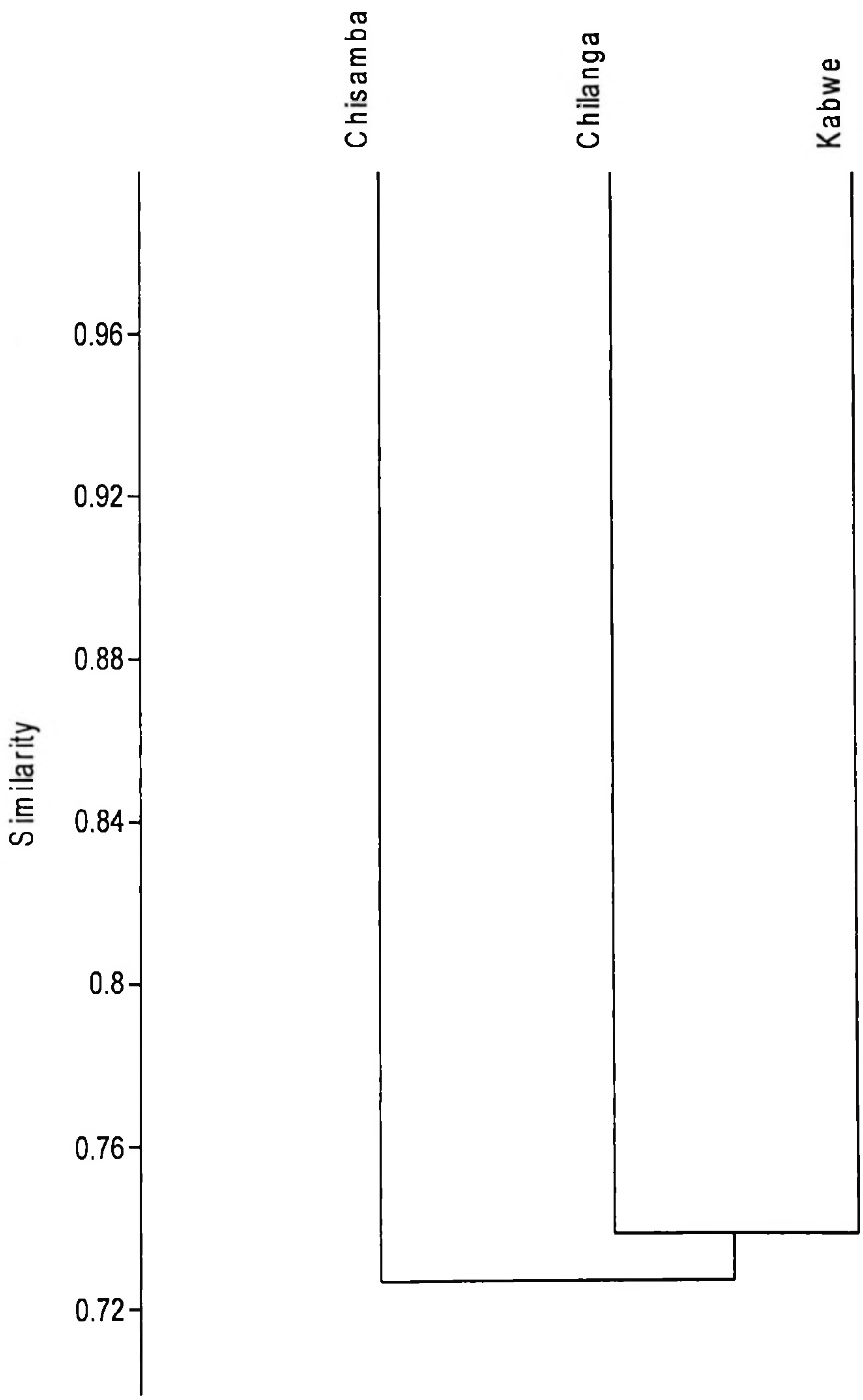


Figure 2: Dendogram showing the constrained Ochiai's index of similarity among three study sites in Central Zambia

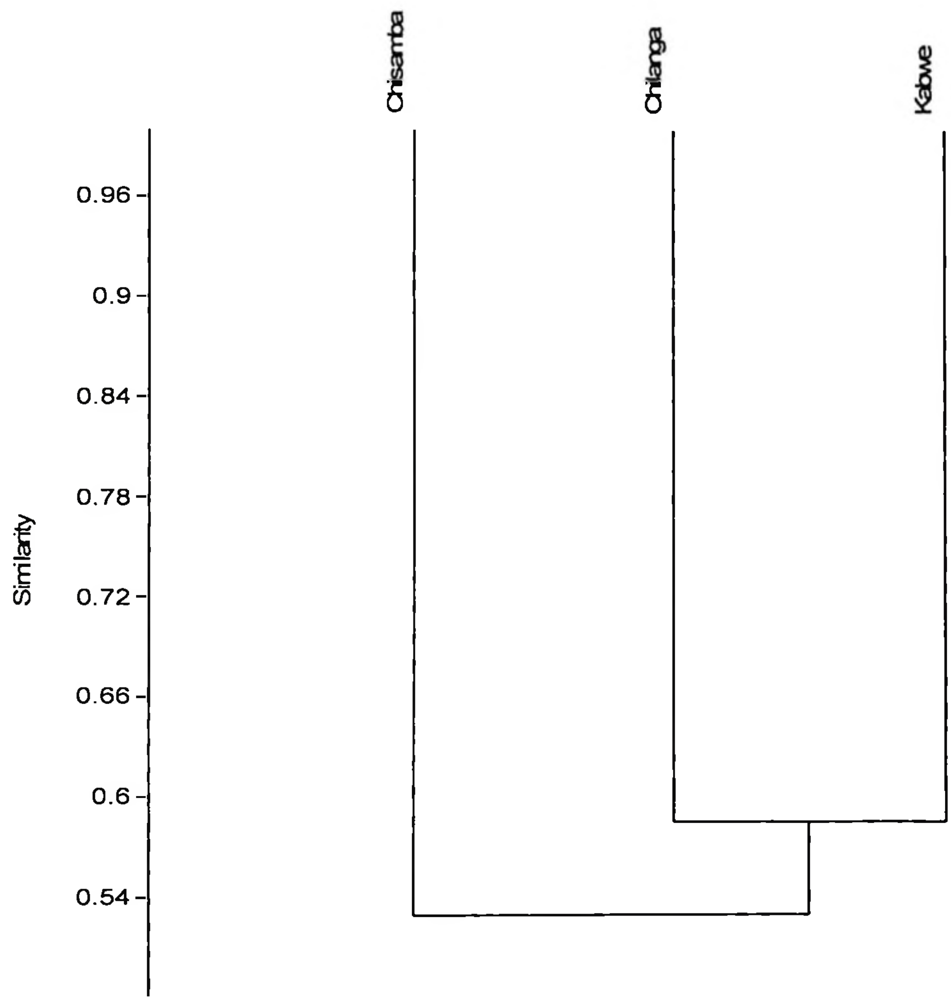


Figure 3: Dendrogram showing the Jaccard's index of similarity among the three study sites in Central Zambia

4.1.2 Infestation rate of fruit flies attacking pumpkin

The infestation rate of fruit flies in pumpkins during the 2010/11 cropping season from Central Zambia is summarised in Tables 5. The highest infestation rate was 24.4 fruit flies/ kg of pumpkin fruits for *D. ciliatus* while the lowest infestation rate recorded was 1.6 flies/ kg for *D. vertebratus* (Table 5). Similarly, the fruit flies infestation rate calculated based on the number of fruit flies per fruit gave similar ranking (Table 5).

Table 5: Infestation rate of dominant fruit flies on pumpkin in Central Zambia

Species	Total number of fruits harvested	Total weight of fruits harvested (kg)	Number of fruit flies emerged	Minimum number of flies	Maximum number of flies	Infestation rate (number of flies/ fruit)	Infestation rate (number of flies/ kg)
Dacus bivittatus	99	20.1	358	1	110	3.6	17.8
Dacus ciliatus	99	20.1	490	2	395	4.9	24.4
Dacus vertebratus	99	20.1	32	1	19	0.3	1.6

4.1.3 Distribution and seasonal abundance of fruit flies of cucurbits in Zambia

Distribution of fruit flies in Zambia

The detection survey using Chempack traps was conducted along major transects to determine distribution of cucurbit infesters in Zambia. The survey targeted cucurbit infesters that are attracted to CL and it revealed a capture of 11 fruit fly species. The Genus *Dacus* was represented by 9 species while the other 2 were from the Genus *Ceratitis*. During the detection survey, 22 sites were visited as summarised in Table 6. The fruit fly species detected were as listed in Table 7. The most frequent and abundant species detected in all the sampled sites was *D. bivittatus*, a species of known economic importance for cucurbits production and attracted to CL. The known lure for *D. vertebratus* is Vert Lure while *D. ciliatus* has no known lure. Hence, the distribution of *D. bivittatus* was statistically analysed. The analysis showed that the distribution of *D. bivittatus* in Zambia deviated from a random Poisson distribution. The calculated coefficient of distribution or ID (2589.766) of *D. bivittatus* was greater than the Chi square value (32.67) as shown in Table 7. Therefore, fruit fly occurrence in Zambia is not evenly distributed.

Seasonal abundance of cucurbit infesters

From the detected cucurbit infesters (Table 7), seasonal abundance for *D. bivittatus* was observed due to its positive response to CL. The one way analysis of variance (ANOVA) revealed insignificant seasonal differences in the mean monthly catches of *D. bivittatus* ($F_{2,6\,;\,0.05} = 1.12$; $p = 0.3855$). The mean monthly fruit fly catches of 202 ± 93.2 for the cool season was not significantly different from the mean monthly fruit fly catches of 120 ± 115.0 and 21 ± 7.8 for the hot season and wet season respectively (Fig. 4).

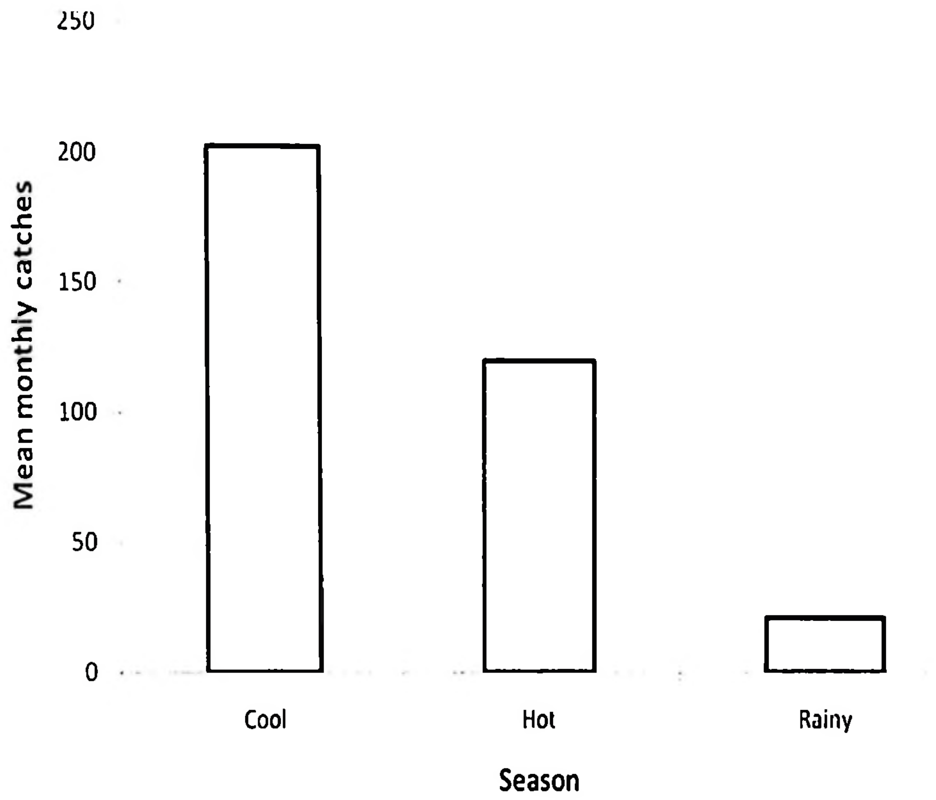
Table 6: Trapping sites at districts along major trunk roads in Zambia

Province	District	Site	Latitude	Longitude	Altitude (m)
Northern	Mpulungu	Kafukula	S8°51'29.5554"	E031°8'34.4904"	985
	Kasama	Misamfu	S10°10'15.657"	E31°13'30.4278"	1 570
	Nakonde	Old Fife	S9°19'49.7346"	E32°46'36.7824"	1 667
Central	Serenje	FRA	S13°13'8.004"	E30°14'10.4712"	1 435
	Kabwe	ZARI	S14°23'45.3726"	E28°29'40.1634"	1 188
	KapiriMposhi	Junction	S13°55'31.0008	E28°40'11.5104"	1 273
	Chibombo	Chisamba	S15°00'39.2364"	E28°11'12.5226"	1 175
	Mumbwa	Mumbwa	S15°01'20.3838"	E27°02'30.0322"	1 192
Lusaka	Lusaka	Chilanga	S15°32'52.1082"	E28°14'54.6930"	1 193
Western	Kaoma	DACOs	S14°47'42.6228"	E24°48'24.66"	1 158
	Mongu	DACOs	S15°16'16.4166"	E23°7'28.0596"	1 066
	Senanga	Council	S16°6'41.8566"	E23°17'49.2462"	1 012
	Sesheke	Katima	S17°28'12.756"	E24o14'28.0248"	1 009
Southern	Livingstone	Amarula	S17°47'14.74"	E25°34'33.86"	1 031
	Choma	Siatunda	S16°49'9.2202"	E26°57'31.3596"	1 332
	Monze	ZCA	S16°17'10.07"	E27°31'07.80"	1 136
	Mazabuka	ZIAH	S15°50'31.43"	E27°43'33.63"	1 031
Northewestern	Solwezi	Mutanda	S12°25'24.2256"	E27°51'27.4746"	1 320
	Kabompo	Boma	S13°25'43.4214"	E24°12'4.77"	1 092
Copperbelt	Mufulira	MTTC	S12°33'53.4132"	E28°13'54.1518"	1 260
	Chingola	DACOs	S12°32'56.9358"	E27°51'27.4746"	1 370
Luapula	Mansa	Kawama	S11°8'54.4986"	E28°53'7.0296"	1 251

Table 7: Countrywide distribution of fruit flies attracted to cue lure

Site	*Dacus bivittatus*	*Dacus punctatifrons*	*Dacus venetatus*	*Dacus famona*	*Dacus eminus*	*Dacus chiwira*	*Dacus africanus*	*Dacus vertebratus*	*Ceratitis cosyra*	*Ceratitis faciventris*	*Dacus kariba*
Kabompo	6	1									
Kapiri Mposhi	111	1	4	4						1	
Serenje	8										
Kasama	10										
Nakonde	4										
Chingola	14	1									
Mpulungu	14										
Mansa	27										
Mufulira	19		4			1					
Solwezi	6										
Mumbwa	54		5					1			
Chilanga	51	5	1		15	14					3
Kabwe	10					7	1				
Chisamba	88										
Mongu	114					22			1		
Kaoma	12			1							
Monze	280		4		27	30		7	2		
Mazabuka	192	4									
Choma	3										
Livingstone	32										
Sesheke	27										
Senanga	304	6			1	10					

Coefficient of distribution (ID) = 2589.77; Chi square value ($\chi^2_{0.05, 21}$) = 32.67 for *Dacus bivittatus*

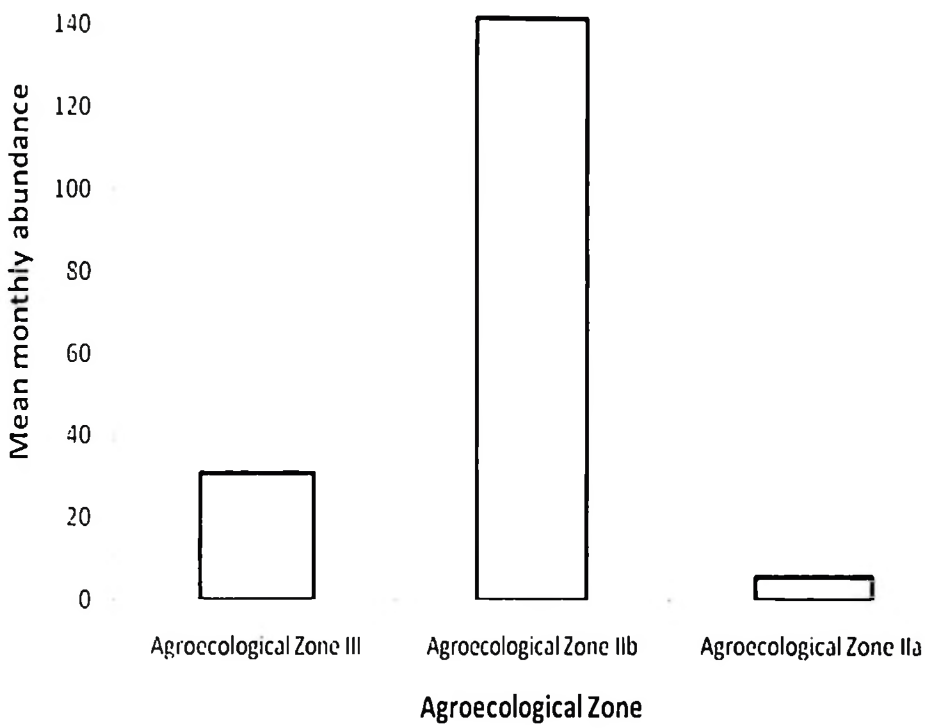


df = 2, n = 3, p = 0.3855, LSD $_{(0.05)}$ = 296.08

Figure 4: Mean monthly catches of *D. bivittatus* in the cool, hot and rainy seasons

Abundance of cucurbit infesters in different agro-ecological regions

The study concentrated on the abundance of *D. bivittatus* based on the earlier on given reasons. The One way analysis of variance (ANOVA) revealed insignificant differences in the mean monthly catches of *D. bivittatus* in different agro-ecological regions ($F_{2,26\,;\,0.05}$ = 13.17; p = 0.0059). The mean monthly fruitfly catches of 31.0 ± 41.03 for AEZ III was not significantly different from the mean monthly fruitfly catches of 142.25 ± 37.46 and 5.86 ± 49.05 for AEZ IIa and AEZ IIb respectively (Fig. 5). The least significance revealed that AEZ IIb was significantly different from AEZ IIa while AEZ IIb and III were not significantly different.



df = 2, n = 3, p = 0.0059, LSD $_{(0.05)}$ = 131

Figure 5: Mean monthly catches of *D. bivittatus* in Agro-ecological regions

4.1.4 Influence of climate on abundance of D. bivittatus

Regression analysis of the influence of maximum temperature (°C), minimum temperature (°C), mean monthly rainfall (mm) and relative humidity (%) on the abundance of *D. bivittatus* revealed that only minimum temperature had a significant influence on fruit fly abundance. Correlation analysis revealed that there was a negative relationship between temperature and rainfall and fruit fly abundance. There was a positive relationship between relative humidity and fruit fly abundance. These results are summarised in Table 8. Figures 6 to 9 show the log linear models for predicting *D. bivittatus* from abiotic factors.

Table 8: The correlation between abiotic factors and number of adult male *D. bivittatus* trapped with Cue lure

Abiotic factor	Regression equation	r^2	F value	P value
Maximum temperature (°C)	y = -2.6577x +149.42	-0.06	$F_{1,27} = 0.09$	0.7653
Minimum temperature (°C)	y = -13.534x +268.28	-0.396	$F_{1,27} = 5.013$	0.033
Rainfall (mm)	y = -0.372x +103.3	-0.297	$F_{1,27} = 2.619$	0.117
Relative Humidity (%)	y = 0.863x – 31.251	0.442	$F_{1,10} = 2.426$	0.1504

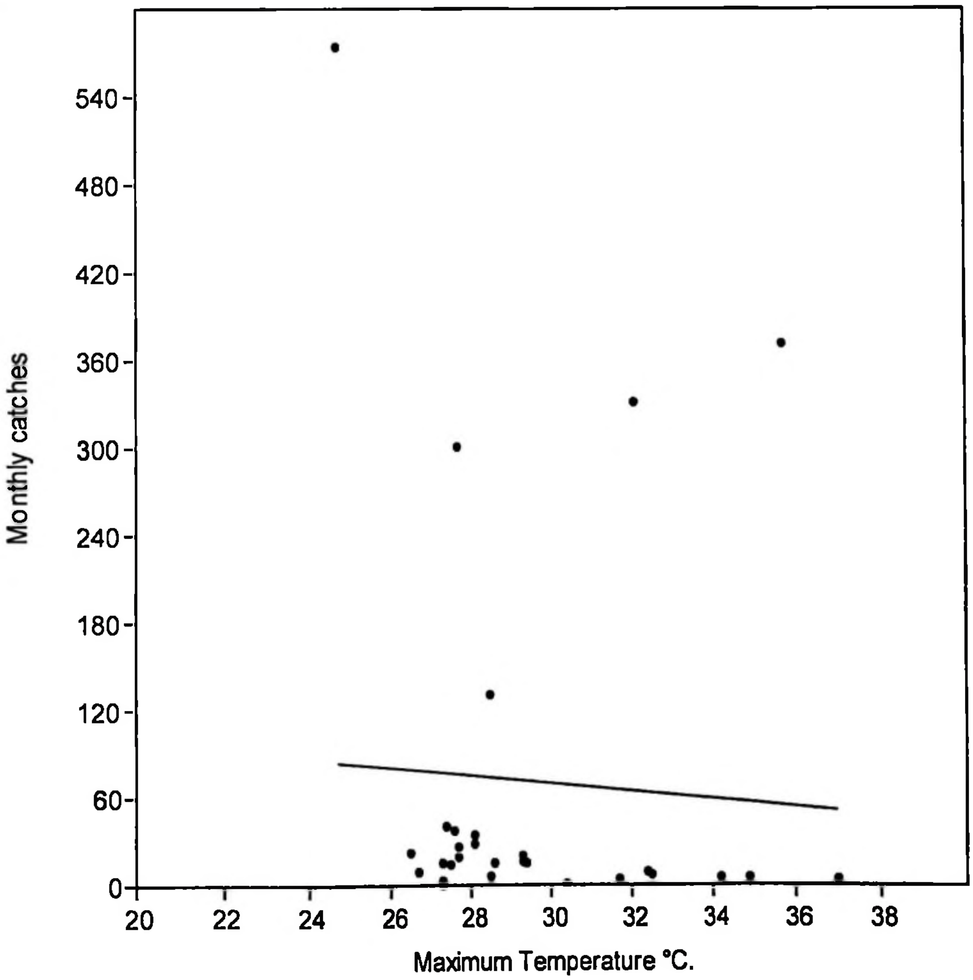


Figure 6: Scatter diagram of maximum temperature and monthly catches of *D. bivittatus*

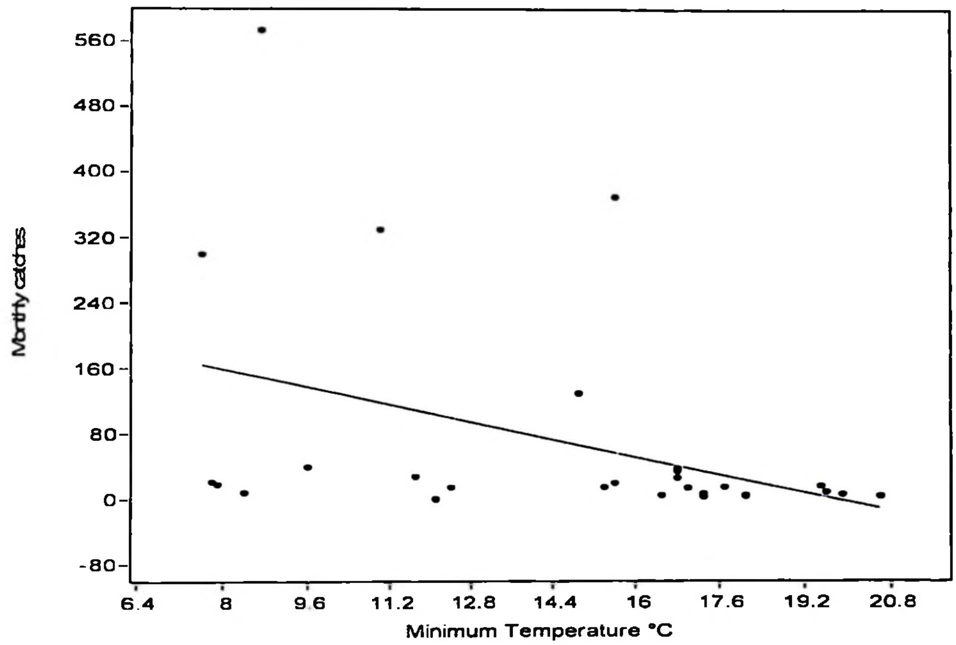


Figure 7: Scatter diagram of minimum temperature and monthly catches of *D. bivittatus*

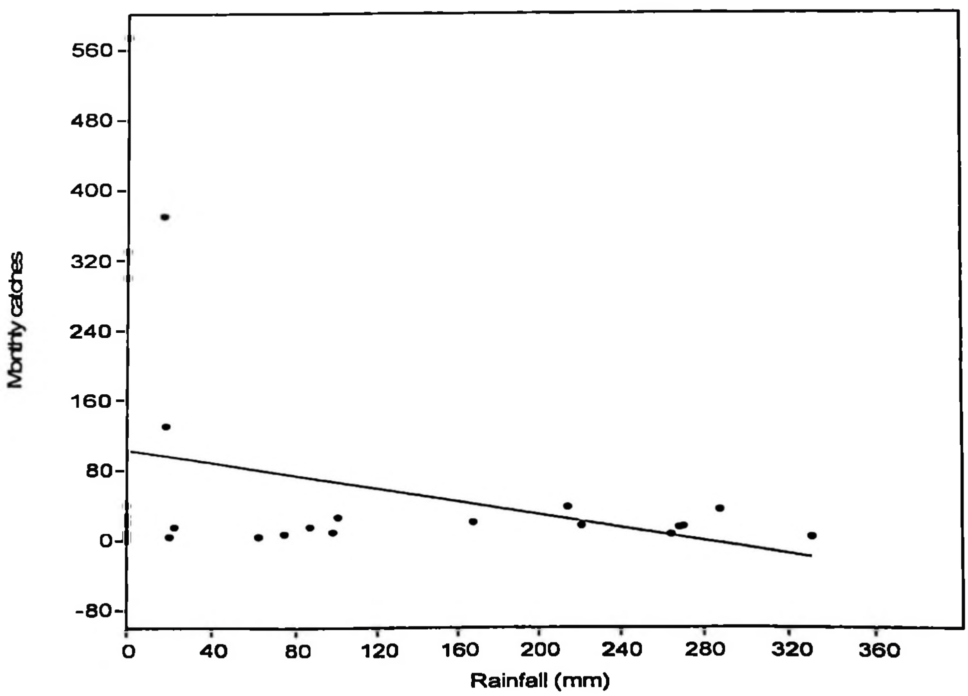


Figure 8: Scatter diagram of mean monthly rainfall and monthly catches of *D. bivittatus*

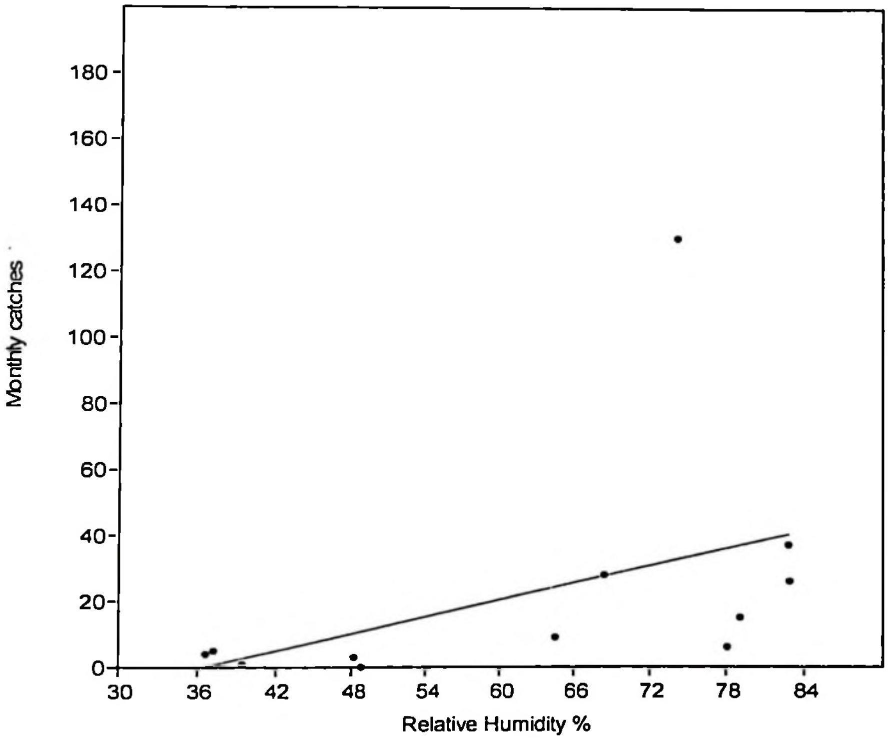


Figure 9: Scatter diagram of relative humidity (RH) and monthly catches of *D. bivittatus*

4.1.5 Development of a model to predict potential distribution of cucurbit infesters in Zambia

The potential distribution of an invasive cucurbit infester, *B. cucurbitae*, in Zambia was developed using CLIMEX software. The CLIMEX parameter values that best described the reported distribution of *B. cucurbitae* are shown in Table 9. The temperature indices (DV0, DV1, DV2, DV3) and degree days per generation (PDD) as shown in Table 9 were set based on the review of Dhillon et al. (2005) and work of Vayssieres *et al.* (2008). Plate 8 shows the locations in Zambia in which *B. cucurbitae* population was predicted to grow. The areas of circles on the map are proportional to the ecoclimatic suitability for the population growth of *B. cucurbitae.* Western and Southern parts of Zambia show higher ecoclimatic index (EI) values for the establishment of *B. cucurbitae*, 37 and 31 respectively with the highest number of generations too (Table 10). Northwestern and Central parts of the country showed the lowest EI values of 21 and 22 respectively. Validation of the model indicated that it fits the predicted and known occurrences of *B. cucurbitae* in Asia as shown in Plates 9 and 10 respectively.

Table 9: CLIMEX Parameter Values for *Bactrocera cucurbitae*

Parameter	Mnemonic	Value
Limiting low temperature	DV0	8.1 °C
Lower optimal temperature	DV1	11.4 °C
Upper optimal temperature	DV2	32.2 °C
Limiting high temperature	DV3	36.4 °C
Cold Stress Temperature Threshold	TTCS	10 °C
Cold Stress Temperature Rate	THCS	0
Cold Stress Degree-day Threshold	DTCS	5 °C
Cold Stress Degree-day Rate	DHCS	- 0.0015 week^{-1}
Cold Stress Temperature Threshold (Average)	TTCSA	0
Cold Stress Temperature Rate (Average)	THCSA	0
Heat Stress Temperature Threshold	TTHS	39°C week^{-1}
Heat Stress Temperature Rate	THHS	0.01week^{-1}
Heat Stress Degree-day Threshold	DTHS	100°C
Heat Stress Degree-day Rate	DHHS	0
Dry Stress Threshold	SMDS	0.02
Dry Stress Rate	HDS	-0.05 week^{-1}
Wet Stress Threshold	SMWS	1.6
Wet Stress Rate	SMWS	0.0015 week^{-1}
Degree-days per Generation	PDD	397.8°C

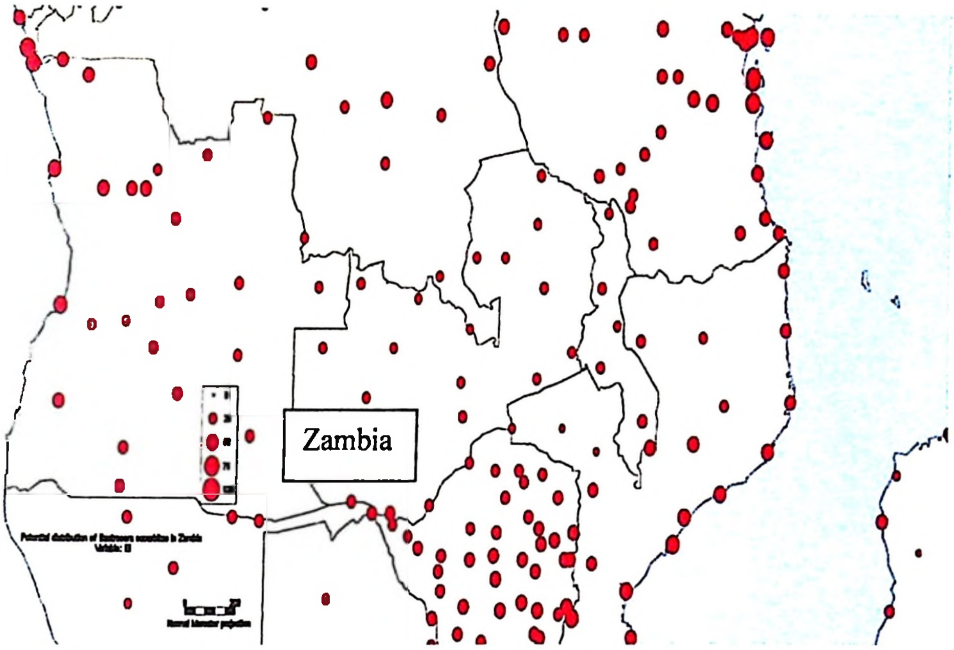


Plate 8: Predicted ecoclimatic suitability for potential distribution of *B. cucurbitae* in Zambia using CLIMEX

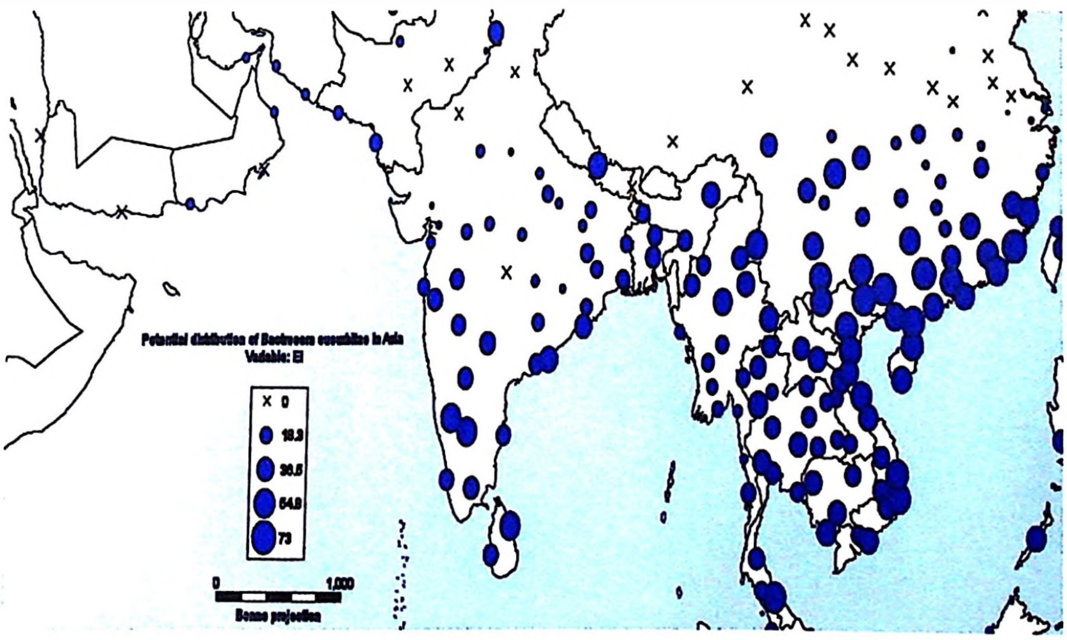


Plate 9: Predicted ecoclimatic suitability for potential distribution of *B. cucurbitae* in Asia using CLIMEX

Plate 10: Known native and introduced distribution of *B. cucurbitae* in Asia

Source CABI (2011)

Table 10: Compare location for the potential distribution of *Bactrocera cucurbitae* in Zambia

Location	Generation	Altitude (m)	Core Distribution	Degree Days (DD)	Ecoclimatic Index (EI)	Growth Index (GI)	Longitude	Latitude
Chilubi	12.34	1 177	93	4 907	23	25	30.000	-11.100
Chipata	12.64	1 032	91	5 028	25	28	32.600	-13.600
Kabwe	11.40	1 207	93	4 534	25	27	28.400	-14.400
Kaoma	11.73	1 132	89	4 668	25	28	24.800	-14.800
Kasama	11.41	1 384	96	4 541	24	25	31.200	-10.200
Kasempa	10.89	1 234	90	4 330	22	24	25.800	-13.500
Livingstone	12.87	986	92	5 118	37	40	25.800	-17.800
Lusaka	11.33	1 154	92	4 507	28	30	28.500	-15.300
Mansa	11.26	1 253	94	4 480	24	26	28.900	-11.100
Mbala	10.56	1 673	97	4 201	29	30	31.300	-8.900
Mongu	13.18	1 053	86	5 244	24	28	23.200	-15.300
Mpika	10.48	1 402	98	4 168	28	28	31.500	-11.900
Mwinilunga	10.82	1 363	98	4 302	26	27	24.500	-11.800
Ndola	10.74	1 270	90	4 273	20	22	28.700	-13.000
Petauke	12.83	1 028	92	5 106	25	27	31.300	-14.300
Sesheke	12.21	946	86	4 855	31	36	24.300	-17.500
Solwezi	10.69	1 378	91	4 252	21	25	26.700	-12.200
Zambezi	12.66	1 078	92	5 038	25	28	23.100	-13.500

4.2 Discussion

4.2.1 Species composition and diversity

Virgillio *et al.* (2011) in their study on quantitative comparison of frugivorous tephritids in tropical forests and rural areas of Democratic Republic of Congo (DRC) reported 29 species from seven genera. The three most abundant species sampled included *D. bivittatus*, *D. punctatifrons* and *B. invadens* showed significant variations in abundance across locations and sites and accounted for 98.29% of the overall dissimilarity between habitats. However, based on the collected data, they concluded that in rural villages of central Democratic Republic of Congo, human activities, such as small-scale agriculture and local commerce, are not always sufficient to promote differences between the tephritid assemblages of villages and those of the surrounding tropical forests.

Comparing the species composition of fruit flies collected in a study on biodiversity of frugivorous flies (Diptera: Tephritoidea) captured in citrus groves, Mato Grosso do Sul in Brazil with similar studies conducted in other Brazilian regions, Uchoa-Fernandes *et al.* (2003) observed remarkable differences. They attributed the difference to climate and floristic composition peculiar to each biome. Temperature above 34°C negatively affect pupariation due to increased desiccation while temperature below 15°C affect the physiology of the flies. Fruiting period of the host plants and optimum temperature exert essential influence on the fruit fly population.

The fruit fly fauna of Central Zambia is not yet fully known. However, with lure trapping and rearing from infested hosts some valuable information has been attained. In this study, the observed differences in species composition of fruit flies attacking cucurbits in Central Zambia may be caused by pesticides application. Chisamba area has more commercial farmers of cucurbits who frequently use pesticides for pest control as compared to Kabwe and Chilanga. During data collection, it was observed in Chisamba that pesticides were applied in the morning time based on calendar dates. Probably, this could have resulted in the eradication or migration of other fruit flies species from the area. In Kabwe and Chilanga sites, it was observed during data collection that crop sanitation was not practiced by farmers who grew cucurbits due to lack of sufficient knowledge about fruit flies. Thus, contributing to the resident reservoir of fruit flies species in these areas. This concurred with Vijaysegaran (1985) who reported that orchard sanitation by collecting and destructing all unwanted fruits on the trees and on the ground contributes extensively to reducing the fruit fly population. The higher species diversity in Chilanga could probably indicate the diversity of plant species comprising members belonging to the Malvaceae, Solanaceae, Rutaceae, Anacardiaceae, Fabaceae and Cucurbitaceae families (White and Elson-Harris, 1994; Mwatawala *et al.*, 2006). Other reasons that influenced the similarity of the sites could also be proposed such as lack of natural enemies and species competition (Duyck *et al.*, 2006).

The detected fruit flies species of economic importance in this study have been recorded to be present in Zambia by White and Elson-Harris (1994), CABI (2007) and Thompson (1998). The invasive exotic fruit fly *B. cucurbitae* was not detected. Nevertheless, this study has recorded the presence of major indigenous species of economic importance in Central Zambia which pose a threat to cucurbit production and need further investigations for their host range.

4.2.2 Infestation rate of fruit flies in Central Zambia

Jackson *et al.* (2003) in their investigation to further determine the levels of infestation of *Coccinia grandis* by melon flies in the Kona region of Hawaii Island and to determine the natural parasitism levels on melon flies by the parasitoid *Psyttalia fletcheri* (Silvestri), reported a significant variation among sites in the percentage of fruit infested with melon fly. They concluded that the considerable variation in their data over dates and sites showed that collections should be made over several dates and at several sites to get a good estimate of infestation.

Infestation rate may be affected by competition among the tephritid larvae. Interference between larvae may take the form of physical attacks, cannibalism, or elimination by fruit deterioration. Whatever the mechanism, the first larvae to hatch in a given fruit will have an advantage over subsequent larvae (Fitt, 1989). Qureshi *et al.* (1987) demonstrated the impact of cross-infestation on larva development in two species that live on the Cucurbitaceae *B. cucurbitae* and *D. ciliatus* while Keiser *et al.* (1974) worked on *C. capitata* and *B. dorsalis*.

These experiments showed that the competitive advantage observed in the wild can partly be predicted by a better survival of larvae in laboratory conditions.

According to White and Elson- Harris (1994), some tephritids such as *C. capitata* use pheromones to mark the fruits in which they have oviposited as signal to other members of the same species that the host has already been attacked. This has to be established for *Dacus* spp. as well.

Khan *et al.* (2005) reported that weather factors played significant contribution towards population fluctuation and infestation rate of fruit flies in apple, guava and mango orchards, whereas in orchards of 'ber' these factors remained non-significant towards population fluctuation and infestation. Weather factors when computed together contributed significantly towards population fluctuation and infestation with rainfall exerting a positive influence.

In this study, *D. ciliatus* is shown to have the highest infestation rate of compared *D. bivittatus* and *D. vertebratus*. This could be due to the match in the fruiting period of pumpkins and higher survival rate of larvae. In the case of simultaneous laying of eggs of two or more Dacini species, the competitive advantage of either of the fruit fly can be explained by its shorter egg incubation period and its shorter duration of immature stages. The importance of competitive preemption has recently been shown among four polyphagous tephritids attacking fruit crops in Reunion (Duyck *et al.* 2006).

The infestation rates for cucurbit infesters recorded on pumpkin in Tanzania by Mwatawala *et al.* (2006) were generally higher than the ones recorded in this study due to difference in the altitude. However, in Tanzania *D. ciliatus* showed the highest infestation rate compared to *D. bivittatus* and *D. vertebratus*. Similar results were observed by Mwatawala *et al.* (2009) in their study on *Bactrocera* invasions and their speculated dominancy on native fruit fly species in Tanzania. They observed that the infestation rate for *D. ciliatus* on pumpkin was the highest with *D. punctatifrons* showing the lowest. Numerical dominancy was attributed to competitive ability of the fruit fly species and demographic strategy is a main component of relative successful competition for different species (Vayssie`res *et al.*, 2008). The short preoviposition and incubation period including greater reproductive potential are attributes of *D. ciliatus* for dominance. Review by Jayesankar (2009) noted that *D. ciliatus* oviposites on early fruit stages of development.

The present findings however, cannot be compared with the works of Stonehouse *et al.* (2007) and Sapkota *et al.* (2010) due to the differences in their materials and methods. Further studies will be needed on larval interspecific competition in this complex of cucurbit infesters in order to understand the performance of each species in situation of co-infestation.

4.2.3 Distribution and seasonal abundance of fruit flies of pumpkin in Zambia

Novotny *et al.* (2005) study on host specialisation and species richness of fruit flies in a New Guinea rainforest found that the distribution of fruit fly species richness corresponds to a Poisson random distribution. They postulated that the distribution of fruit fly species richness among host species approaching the Poisson distribution is consistent with the model of host colonisation in an ecosystem where all plants have the same probability of being colonized by a new fruit fly independent of the number of fruit fly species they already support.

Traditionally, the distributions and abundances of frugivorous tephritid pests have been strictly related to human-mediated activities, such as agriculture, (inter)national trade of fruit and plant products, tourism, and movements of military troops and refugees (Virgilio *et al.*, 2010).

Mwatawala *et al.* (2010) reported the occurrence of *B. cucurbitae* in the Morogoro Region to be limited to medium altitude due to its preference for warmer conditions. Similarly, Vayssieres *et al.* (2008) reported *B. cucurbitae* to be found at low and medium altitude in the Reunion Island where it competed with the Ethiopian cucurbit fly *D. ciliatus* and both competing with the indigenous Ocean cucurbit fly, *Dacus (Dacus) demerezi* (Bezzi) that occupy higher altitude areas. The data from their studies supported the hypothesis that elevation and host fruit availability affect the distribution of fruit flies. Host suitability for the survival of larvae is influenced by the presence of secondary compounds such as latex and toxins which may reduce growth rates or are toxic to the larvae and bacteria.

Drew and Hooper (1983) reported that the seasonal activity of *Dacus cacuminatus* (Hering) was dependent upon temperature, rainfall and the state of development of the host plant. This species shows an ability to exploit its host and to increase rapidly in numbers when environmental conditions permit. The fly populations increased with the onset of higher temperatures and the beginning of the summer rain period and decreased with the decline in temperature and rainfall in autumn. Studies on *D. cacuminatus* showed that when environmental conditions are suitable this species efficiently exploits its host resulting in rapid population increases. Comparable studies on the Oriental Fruit Fly (*B. dorsalis*) by Tan and Serit (1994) suggested that fruit fly populations were affected directly by host fruit availability.

In the present study, the distribution of *D. bivittatus* in Zambia was found to be random. This could be attributed to the migration of adult flies in search of hosts and its ability to adapt to different types of environment. However, this distribution pattern is in agreement with the unseasonal countrywide production of cucurbits. Therefore, understanding the range of host plants and their fruiting cycles is a key factor and of great importance in explaining distribution and population fluctuations of this fruit fly species.

Host availability has shown to have an impact on seasonal abundance of fruit flies as shown in the review by Vinatier *et al.* (2011). The mean monthly catches for *D. bivittatus* were seen to be highest during the cool season (May to July). These findings corroborate with most cucurbit phenology grown during this season. Most small scale farmers avoid sole planting of cucurbits during the wet season due to a high prevalence of fungal and bacterial diseases as opposed to the cool season. Similar findings were reported in Tanzania for *B. cucurbitae* by Mwatawala *et al.* (2010).

Influence of climatic factors on fruit fly abundance

Information of population dynamics and the related ecological factors must be jointly gathered, in order to make it possible to carry out an appropriate pest control at the right time and place (Jiang *et. al.* 2008). Fruit fly species exhibit different population dynamics across and within species. Dynamics may be seasonal in which the parameters change in the consistent manner with the time of the year or they may be aseasonal, in which irregular patterns occur during the year (Wolda, 1988). The influence of abiotic factors such as temperature and rain is closely related with fly distribution as well as their population dynamics (Duyck *et al.*, 2006). Manzar and Srivastava (2004) reported a significant correlation of population of *B. zonata* with minimum temperature. The number of fruit flies captured with CL baited traps correlated positively with all three abiotic factors, i.e. temperature, humidity and rainfall (Hasyim *et al.*, 2008).

Vayssieres *et al.* (2005) in their investigation on fluctuations of tephritid populations in orchards and to assess mango fruit fly infestations and mango losses due to tephritid species, reported that the population of *B. invadens* increases with rise in temperature and rainfall. Similar observation with regard to influence of meteorological parameters on the incidence of melon fly was also claimed earlier by other workers (Mahmood *et al.*, 2002).

Mwatawala *et al.* (2010) reported that the peak populations of *B. cucurbitae* were recorded during the dry period, when temperatures and relative humidity were low. This was attributed to the availability of hosts grown under irrigation system during this period rather than climatic factors as such. A non-significant relationship between number of males captured per trap per day averaged over each month and average monthly temperature and rainfall was found at a regional level (Black River and Pamplemousses districts included) in Mauritius. At the district level however, Pamplemousses had a significant correlation coefficient (r=0.91, p<0.05) between average monthly temperature and average trap catch per day (Manrakhan and Price, 2001). Duyck *et al.* (2006) in their review noted that the main biological characteristics of each Tephritidae species are the determining factors in their population dynamic. Longevity, reproduction rate, fertility, range of host plants and speed of development of the juvenile stages as a function of abiotic factors are what actually determine the result of possible inter-species competition for sympatric Tephritidae species.

According to the results of this study, generally the population dynamics of *D. bivittatus* was not significantly affected except by minimum temperature. The regression model of maximum temperature on monthly catches was not significant; however, the negative relationship indicates that as maximum temperature increases, the monthly catches of *D. bivittatus* decreases.

The regression model of minimum temperature on monthly catches was significant. The negative relationship between minimum temperature and abundance of *D. bivittatus* shows that as minimum temperature increases, the abundance of fruit flies decreases. This is so because most cucurbits are grown during the cool season when there is reduced pests incidence. Results in this study are different from other as more time was needed to develop a significant model.

Influence of agro-ecological zones on fruit fly abundance

Mwatawala *et al.* (2006) investigated the temporal occurrence of *B. invadens* in three agro-ecological areas of Morogoro Region, Tanzania, during 2004– 2005. Weekly and monthly trappings were carried out using various attractants. They reported permanent presence of *B. invadens* at low and mid-altitudes (380–520 meters above sea level [masl]) with peak periods coinciding with the fruiting season of mango and guava. At high altitude (1650 masl) its incidence was only temporal and thought to be as a result of dispersal from lower altitudes after the end of the mango fruiting season. The study on fruit fly species diversity in three remnant areas of the highly endangered Atlantic Rainforest of the state of Bahia in Brazil showed that the capture of flies was restricted to the fruiting period of the host plants in the three fragments (Silva *et al.*, 2010).

In this study, there was insignificant difference of fruit flies abundance in the agro-ecological zones. However, AEZ IIa almost showed some significant difference (p = 0.00059). This could be due to availability of irrigation facilities in this area which enable a bigger number of farmers to grow various species of cucurbits throughout the year. The availability of cucurbits throughout the year supports the prevalence of fruit flies populations throughout the year.

4.2.4 Predicted distribution of B. cucurbitae in Zambia

Cobos-Suarez *et al* (2010) predicted the potential geographic distribution of peach fruit fly (PFF), *B. zonata,* for Europe and the Mediterranean Basin using CLIMEX modeling package. They noted that the locations within the areas of origin of the PFF were not climatically similar. This could have suggested that the Indian and Pakistan populations could have different climatic requirements. Stephens *et al.* (2007) predicted suitable climatic conditions the distribution of *B. dorsalis* throughout the tropic and sub-tropics with the exception of desert areas where dry stress and/or hot stress limit its distribution. However, potential distributions cannot be predicted based on climate alone; and there is a need to consider dispersal and species interactions, use of pesticides, host availability, competition and the effect of natural enemies.

In this study, the prediction of the potential distribution of *B. cucurbitae* was based on lethal low and high temperature including moisture stress. The drought prone areas like some southern parts of Zambia are seen to be less suitable due to high prevalence of high temperature and low rainfall. The study is in agreement with the distribution of *B. cucurbitae* in Africa (De Meyer *et al.*, 2007; Mwatawala *et al.*, 2010; Vayssie`res *et al.*, 2007). This study cannot be compared with the work of De Meyer *et al* (2010) due to the difference in the materials and method. Therefore, Pest risk maps must be interpreted with a full understanding of what the map seeks to portray and the assumptions embodied in the underlying model. Maps of the potential distribution of an invasive alien species do not necessarily correspond with the areas where such species will have the greatest impact, or with the areas most likely to be invaded first. Thus, maps often reflect components that contribute to overall pest risk, but not the risk in its entirety. CLIMEX is a strategic and not tactical tool which is species and location specific. It can be used to prioritise sites to be covered for pest detection survey thereby saving time and money for plant protection agencies.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Fruit and vegetable production is one of the fastest growing agriculture sector in Zambia due the population growth and expansion of the hospitality industry. However, different pests afflict production and productivity of the industry thereby having a negative impact on household and national food security besides disrupting trade. Strategic and tactical decisions for the management of pests depend on accurate biological, spatial and temporal characterizations of pest risk. It is upon this consideration that the study assessed the impact of fruit flies on pumpkin production in Zambia. Therefore, the study came up with following conclusions:

i. Preliminary data show that central Zambia has the highest diversity of cucurbit infesters.
ii. The fruit flies infesters of cucurbit are distributed throughout Zambia.
iii. The infestation rates (flies/fruit and flies kg^{-1}) are high.
iv. The abundance of cucurbit infesters in the study area is largely influenced by host availability compared to climate.

5.2 Recommendations

The following recommendations are made from the study:

i. Although the current study established a wide range of fruit flies infesters of cucurbits in central Zambia than before, more systematic surveys should be done over a longer period of time in order to detect other fruit flies that are not attracted to synthetic attractants.

ii. Host preference studies of cucurbit infesters and economic impact should be done.

iii. The population abundance was influenced by temperature, detailed study on the effect of all climatic factors should be studied over a longer period of time.

iv. Work on locally available materials for attractants should be done in order to come up with a viable integrated pest management package for small scale farmers.

v. Awareness creation for farmers on the ecological management of fruit flies should be done throughout the country.

vi. Due to the diversity of fruit flies detected, an integrated pest management program should take all species of economic importance into consideration. The package should include: Fruit bagging, use of ecological selectivity pesticides, perimeter trapping, stimulo-diversion deterrent, sanitation and post harvest treatment for cross border traders.

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APPENDICES

Appendix 1: One-way ANOVA for seasonal abundance of fruit flies

One-Way AOV for: Cool Hot Rainy

Source	DF	SS	MS	F	P
Between	2	49286	24643.0	1.12	0.3855
Within	6	131776	21962.7		
Total	8	181062			

Grand Mean 114.33   CV 129.62

Homogeneity of Variances	F	P
Levene's Test	2.14	0.1983
O'Brien's Test	0.95	0.4371
Brown and Forsythe Test	0.63	0.5624

Welch's Test for Mean Differences

Source	DF	F	P
Between	2.0	1.79	0.3199
Within	2.7		

Component of variance for between groups   893.444
Effective cell size   3.0

Variable	Mean
COOL	202.00
HOT	120.00
RAINY	21.00

Observations per Mean   3
Standard Error of a Mean   85.562
Std Error (Diff of 2 Means)   121.00

LSD All-Pairwise Comparisons Test

Variable	Mean	Homogeneous Groups
COOL	202.00	A
HOT	120.00	A
RAINY	21.000	A

Alpha   0.05   Standard Error for Comparison   121.00
Critical T Value   2.447   Critical Value for Comparison   296.08
There are no significant pairwise differences among the means.

Appendix 2: One-way ANOVA for abundance of cucurbit infesters in different agro-ecological zones

One-Way AOV for: AEZI AEZIIa AEZIIb

Source	DF	SS	MS	F	P
Between	2	106624	53311.9	3.17	0.0588
Within	26	437801	16838.5		
Total	28	544425			

Grand Mean 70.966   CV 182.85

Homogeneity of Variances	F	P
Levene's Test	4.18	0.0267
O'Brien's Test	3.79	0.0361
Brown and Forsythe Test	2.96	0.0694

Welch's Test for Mean Differences

Source	DF	F	P
Between	2.0	4.83	0.0259
Within	13.6		

Component of variance for between groups   3860.33
Effective cell size   9.4

Variable	N	Mean	SE
AEZI	10	31.00	41.035
AEZIIa	12	142.25	37.459
AEZIIb	7	5.86	49.046

LSD All-Pairwise Comparisons Test

Variable	Mean	Homogeneous Groups
AEZIIa	142.25	A
AEZIII	31.000	AB
AEZIIb	5.8571	B

Alpha   0.05   Standard Error for Comparison   55.561 TO 63.948
Critical T Value   2.056   Critical Value for Comparison   114.21 TO 131.45
There are 2 groups (A and B) in which the means are not significantly different from one another.

Appendix 3: Determination of distribution of *Dacus bivittatus* in Zambia

	x	x^2	
Monze	280	78400	
Mazabuka	192	36864	
Choma	3	9	
Livinstone	32	1024	
Sesheke	27	729	
Mongu	114	12996	
Senanga	304	92416	
Chisamba	88	7744	
Chilanga	51	2601	
Kabwe	10	100	
KapiriMposhi	111	12321	
Serenje	8	64	
Mumbwa	54	2916	
Kaoma	12	144	
Kabompo	6	36	
Mufulira	19	361	
Solwezi	6	36	
Mansa	27	729	
Mpulungu	14	196	
Nakonde	2	4	
Chingola	14	196	
Kasama	10	100	
SUM	**1384**	**249986**	**SUMSQ**
SQSUM	1915456		
SQSUM/N	87066.18		
SS	162919.8		
S^2	7758.087		
	7758.087		
MEAN	62.90909		
	62.90909		
ID	2589.766		