DEVELOPMENTAL BIOLOGY OF FRUIT FLY (DIPTERA: TEPHRITIDAE) SPECIES ATTACKING CUCURBITS

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ABSTRACT

Fruit flies are among the major pests of cucurbits in many parts of Tanzania. Studies on fruit flies (Diptera: Tephritidae) attacking cucurbit in Morogoro were conducted at Sokoine University of Agriculture (SUA). Objectives of the studies were: to compare incidences and infestation rates of selected fruit fly species in different stages of cucumber fruit, to establish duration and determine survival of immature stages of *Bactrocera cucurbitae* in selected cucurbitaceous hosts. Cucurbit fruit fly species incidences and infestation rates were determined from fruit flies emerging from fruits harvested in crop museum using standard procedures. Duration and survival of *B. cucurbitae* immature stages were established and determined respectively by observing *B. cucurbitae* immature stages development in watermelon, cucumber and pumpkin at 20, 25 and 30ºC using environmental chamber. High incidence (0.75) was observed in immature cucumber fruits with *B. cucurbitae* while low (0.16) was in mature cucumber with *Dacus frontalis*. High infestation rate (120 flies/kg fruits) was observed in immature fruits by *B. cucurbitae* and low (5 flies/kg fruits) was in mature fruits by *D. frontalis*. Long duration (16.23 days) of *B. cucurbitae* was recorded in pupal stage at 20ºC while short duration (0.99 days) was in egg stage at 30ºC. High (97.72%) and low (76.03%) survivals of *B. cucurbitae* was recorded in egg stage at 30ºC and 20ºC respectively. Among targeted fruit flies *B. cucurbitae* had high incidences and infestation rates in cucumber fruit stages. Duration and survival of *B. cucurbitae* immature stages decreased and increased respectively with increase in temperature. Further studies on incidence and infestation of fruit flies in different cucurbitaceous hosts, agro ecological zones and seasons should be conducted. Relationships on biology of *D. bivittatus* and *D. frontalis* with temperature need to

be studied. The studies will add information on rearing, forecasting and ecological management of fruit flies.

DECLARATION

I, **Abdullah Mohamed**, do hereby declare to the senate of Sokoine University of Agriculture that this dissertation is my original work and has neither been submitted nor concurrently being submitted for a degree award in other Institution.

Abdullah Mohamed Date

(MSc. Crop Science Candidate)

The above declaration is confirmed;

Prof. M.W. Mwatawala Date

(Supervisor)

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DEDICATION

This work is dedicated to:

My beloved parents, Mkiga M. and Ekonga, R. who laid the foundation of my education.

and

My lovely wife, Mwanjia for her tireless encouragement, support and understanding during my research work. I will always love you.

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LIST OF ABREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
CABI	Commonwealth Agriculture Bureau International
COSTECH	Commission of Science and Technology
CV	Coefficient of Variation
FAO	Food and Agriculture Organization of United Nations
Fig	Figure
Kg	Kilogram
L: D	Light: Dark
LSD	Least Significance Difference
Max	Maximum
Min	Minimum
P	Probability
SE	Standard error
spp	Specie
SUA	Sokoine university of Agriculture

TMA	Tanzania Meteorological Agency
USD	United States Dollar

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Fruits and vegetables are an important source of revenue for exporting countries (Kadio *et al*., 2011). Cucumber (*Cucumis sativus* L.), Watermelon (*Citrullus lanatus* Thunb.), and melon (*Cucumis melo* L.) are major crop species in the cucurbit or vine–crop family (the Cucurbitaceae), an important family of flowering plants. Robinson and Decker–Walters (1997) reported that other important cucurbit crops include Loofa (*Luffa acutangula* L.), bottle gourd (*Lagenaria siceraria* Stand.), Chayote (*Sechium edule* Jacq.), Wax gourd (*Benincasa hispida* Thunb.) and Bitter melon (*Momordica charantia* L.).

The cucurbits are of tremendous economic importance and are cultivated throughout the world, from Tropical to Sub Temperate zones. They are consumed in various forms for example, salad (cucumber, gherkins, long melon), main ingredient of sweet (ash gourd, pointed gourd), pickles (gherkins), and deserts (melons) (Rai *et al*., 2008). Cucurbit crops are among the fruits grown in Morogoro region in Tanzania. They are generally a good source of vitamins A and C and various vital minerals (Butani, 1984).

Several biotic factors limit the production and productivity of cucurbits including pests, of which cucurbit fruit fly (*Bactrocera cucurbitae* Coquillett) is one of the most important (Sapkota *et al.,* 2010). Generally, fruit flies (Diptera: Tephtritidae) inflict heavy losses on fruits and vegetable crops because of their phytophagous habits. These losses are caused by different fruit fly species and vary among fruit species and places; hence they are accorded different economic status in different farming systems in the world (Mwatawala *et al.,* 2009).

According to Weems and Heppner (2004) cucurbit fruits and vegetables (family Cucurbitaceae), including cucumbers, melons, pumpkins and gourds, suffer serious damage from fruit flies (Diptera: Tephritidae) and in particular from the *B. cucurbitae.* The female flies puncture the tender fruit with their stout and hard ovipositor laying eggs below the epidermis of the fruits. Four to ten eggs are often layed per fruit each time. Srivastava and Butani (2009) reported that single female fly can lay about two hundred eggs in her life span of eight to ten weeks. In Nepal it is apparent that >50% of the cucurbits are either partially or totally damaged by fruit flies and are unsuitable for human consumption (Sapkota *et al.,* 2010). Hence studies on, incidence, infestation and biology of cucurbit fruit fly species were most important.

1.2 Justification

Fruit flies (Diptera: Tephritidae) cause serious damage on fruit and vegetable crops in most tropical countries (White and Elson–Harris, 1992). Although, many insect pests attack fruits and vegetables, none have garnered greater notoriety than Tephritid fruit flies. According to Kadio *et al.* (2011) fruits in tropical countries are undergoing economic losses due to pest attacks mainly represented by fruit flies (Diptera: Tephritidae). These insect pests cause severe losses in many cucurbitaceous crops like melons, gourds and cucumber that are important in the diet of people. Cucurbit fruit fly (*B. cucurbitae*) is an introduced species from Asia with long established adventives populations in Hawaii, Re´union, and eastern Africa (White *et al.,* 2000) attacking cucurbits together with native species like *Dacus ciliatus* (Loew), *Dacus punctatifrons* (Karsch) and *Dacus bivittatus* (Bigot). Kumar *et al*. (2004) reported that *B. cucurbitae* is a major pest of cucurbitaceous vegetables and fruits in many parts of the world causing losses up to 60%. According to CABI (2005), damage levels of *B. cucurbitae* can be up to 100% of unprotected crop. Pareek and Bhargava (1989) found out that *B. cucurbitae* can cause losses between 64.10% and 89.94%. Currently there are no data on the extent of losses caused by fruit flies in various fruit growing areas in Tanzania.

Vayssieres *et al.* (2008) studied young stage life histories of *B. cucurbitae* at different temperatures (15, 20, 25, and 30°C) in cucumber, pumpkin and squash. The research did not include watermelon which is among the key cucurbit crop infested by cucurbit fruit flies. Furthermore, the study did not give information on survival of each immature stage of the pest in those hosts and temperature regimes. Studies on incidence and host range of *B. cucurbitae* have been done by Mwatawala *et al.* (2010) and it was observed that cucurbit host susceptibility is variable both in commercial and wild hosts, with cucumber and melon being the most important cultivated hosts (incidence and infestation rate, respectively) and *Momordica trifoliata* was the most important wild host. However, the study did not compare damage among different fruit stages. There was a need therefore, of conducting studies on the relationship between developmental time and survival of *B. cucurbitae* in different cucurbitaceous hosts. There was also a need to compare incidences and infestation rates of fruit flies among different stages of cucurbitaceous fruits.

1.3 Objectives

1.3.1 Main objective

The general objective of the study was to assess the damage caused and development of fruit flies infesting cucurbits.

1.3.2 Specific objectives

i. To compare incidences of selected fruit fly species in immature and mature stages of cucumber fruit;
ii. To compare infestation rates of selected fruit fly species in immature and mature stages of cucumber fruit;
iii. To establish developmental duration of immature stages of *B. cucurbitae* in selected cucurbitaceous hosts and
iv. To determine survival rate of immature stages of *B. cucurbitae* in different cucurbitaceous hosts.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cucumber

Cucumber (*C. sativus*) is an important cucurbitaceous vegetable grown almost all over the tropical and subtropical countries of the world (Hassain *et al.*, 2002). The crop is an important vegetable and one of the most popular members of the Cucurbitaceae family. It was domesticated about 3 000 years ago, and is indigenous to India (Robinson and Decker–Walters, 1997).

2.1.1 Botany of cucumber

Cucumber is an annual, deep–rooted (91 cm) crop with tendrils and hairy leaves. The plants may have an indeterminate, determinate, or a compact plant habit. The compact growth habit consists of plants with shorter internodes lengths than those of plants with indeterminate or determinate growth habits (Hector *et al.*, 1994). The leaves are triangular with round lobes the middle lobe being longer than others on either side. Small yellow flowers approximately 15 cm in diameter are born in leaf axils. Several flowering habits exist in cucumbers. It can be monoecious with separate male and female flowers on the same plant, gynoecious or "all–female" that produce only female flowers and parthenocarpic depending on cultivars. Furthermore, Hector *et al.* (1994) found out that most cultivars are monoecious with separate male and female flowers on the same plant. The crop produces mature fruit within two months after sowing. Healthy vines continue to produce marketable fruit for at least a four week period.

2.1.2 Distribution of cucumber

Robinson and Decker–Walters (1997) pointed out that in the 14th and 15th centuries, Portuguese sailors carried cucumbers to West Africa while Spanish explorers brought cucumbers to the New World. Cultivated cucumbers are distributed throughout most temperate and tropical climates and are the fourth most widely grown vegetable crops after tomato (*Lycopersicon esculentum* Mill.), cabbage (*Brassica oleracea* var. *capitata* L.), and onion (*Allium cepa* L.) (Kalloo and Bergh, 1993).

2.1.3 Production requirement of cucumber

Optimal temperature range of 20°C to 25°C is ideal for cucumber crop with growth reduction occurring above 30°C (Valenzuela *et al.*, 2003). According to Agarwal *et al.* (1987) cucumbers are especially susceptible to pest attack when growing conditions are less than ideal. Fertile soils are suitable for the cultivation of cucumber; infertile soils result in bitter and misshapen fruits which are often rejected by consumers (Eifediyi and Remison, 2010).

2.1.4 Cucumber production

Cucumber cultivars are classified as slicers, pickles, gherkins, Middle Eastern, trellis and European greenhouse types (Shetty *et al.*, 2002). Slicing cucumbers are the most widely grown type and popular salad vegetables in Tanzania. The top most cucumber producers in the world are as indicated in (Table 1).

Table 1: Top five world cucumber producers 2010

Country	Production in tones
China	40 709 556
Iran	1 811 630
Turkey	1 739 190
Russia	1 161 870
United states	883 360
Total	**46 305 606**

Source: FAO (2010)

2.1.5 Harvest maturity indices for cucumber

Cucumber is a quick growing vine crop that produces mature fruit within two months after transplanting. The crop is harvested at a range of developmental stages, depending on the intended use. Cucumber fruit should be harvested near full size but before the seeds are fully enlarged and become hard. Greenhouse grown parthenocarpic fruit are harvested 10 to 14 days after anthesis when they are bright green (Kanellis *et al.,* 1988).

The main external indices of harvest maturity of cucumber are fruit size, skin colour and bluntness of fruit spines. Slicing cucumber fruit should be smooth and uniformly dark green, have an appropriate length and have a desirable flavor (Olson *et al.,* 2011). According to Wayne *et al*. (2002) slicing cucumbers are hand harvested one to three times per week depending on weather and stage of growth.

2.1.6 Economic importance of cucumber

Cucumber is a member of the economically important family Cucurbitaceae which includes squash (*Cucurbita* spp.), watermelon, and melon. After tomato (*Solanum* *lycopersicum* L.) and watermelon, cucumber and melon are cultivated more broadly than any other vegetable species (Pitrat *et al*., 1999). Cucumber is an important food source in China (Robinson and Decker–Walters, 1997).

2.1.7 Constraints to cucumber production

Cucumber (*C. sativus*) is susceptible to several pest and diseases that attack the roots, foliage, and fruit. Western Spotted Cucumber beetle (*Diabrotica undecimpunctata*) is an important pest of cucumber. The pest causes damage in the seedling stage by girdling and weakening the stems as well as leaves. At flowering, the insect feed on the flower parts and cause poor pollination or deformed fruit growth. Weems and Heppner (2004) reported that cucurbit fruits and vegetables (family Cucurbitaceae), including cucumbers, melons, pumpkins and gourds, suffer serious damage from fruit flies (Diptera; Tephritidae), and in particular from the melon fly (*B. cucurbitae).* The damage due to this pest cause great economic losses to cucurbit growers (Hassain *et al.*, 2002).

2.2 Watermelon

Watermelon (*C. lanatus*) is the fruit plant originally from a vine of southern Africa. The crop is a member of the cucurbit family (Cucurbitaceae). It is grown commercially in areas with long frost free warm periods (Prohens and Nuez, 2008).

2.2.1 Botany of watermelon

Watermelon is a member of the (*Cucurbitaceae*) family (Namdari, 2011). The root system formation begins prior to emergence of cotyledons to the soil surface and reaches maximum extension by the time of flowering. The crop has highly branching taproot extending up to one miter deep into the soil. The stem is a long, trailing vine reaching five miters or more in length. The vines, especially the younger shoots, are covered with long, woolly hairs protecting the plant from overheating.

2.2.2 Origin and distribution of watermelon

All Citrullus species are originated from Africa with the origin of *Citrullus lanatus* in the Kalahari Desert (Zehra *et al.,* 2011). According to Dane and Liu (2007) Southern Africa is generally regarded as the centre of origin for watermelon. Watermelon is now widespread in all tropical and subtropical regions of the world and is mostly grown for fresh consumption of the juicy and sweet flesh of mature fruit. Watermelon subsequently spread over Africa and to other continents (Prohens and Nuez, 2008). The crop has been grown in Egypt for at least 4 000 years (Huh *et al.,* 2008; Gichimu *et al.,* 2009). Generally, it sells in a niche market, in contrast to Buttercup squash *(Cucurbita maxima* Duch), which is an important commodity crop exported to Japan and Korea (Perry *et al*., 1997).

2.2.3 Production requirements of watermelon

Watermelon crop should not follow watermelon, other cucurbits (such as cucumber, squash or pumpkin), tomato, or peppers for at least three years. Watermelons grow best on non–saline sandy loam or silt loam soils. Light textured fields warm up faster in the spring and are therefore favored for early production. Extensive use of inorganic fertilizer causes reduction in number of fruits, delays and reduces fruit setting, which subsequently delays ripening, and leads to heavy vegetative growth

(Aliyu *et al.,* 2003; John *et al.,* 2004). Very sandy soils have limited water–holding capacities and must be carefully irrigated and fertilized to allow for high yield potential. Watermelon cultivation has been reported to be prevalent in drought–prone, semi–arid areas with an annual rainfall below 650 mm (Mujaju *et al.,* 2010). According to Wakindiki and Kirambia (2011) the crop prefers a hot, dry climate with mean daily temperatures of 22 and 30°C. Maximum and minimum temperatures for growth are about 35 and 18°C respectively (FAO, 2010).

2.2.4 Watermelon production

Watermelon is one of the world most important vegetables, as the crop is reared both for its fruit and the vegetative parts (Schippers, 2000). It is planted from seeds or seedlings, harvested, and then cleared from the field like other vegetables. The top five watermelon producers in the world are as presented in Table 2.

Table 2: Top five world watermelon producers 2010

Country	**Production in tonnes**
China	56 649 725.00
Turkey	3 683 100.00
Iran	3 466 880.00
Brazil	1 870 400.00
United States	1 866 660.00
Total	**67 536 765.000**

Source: FAO (2010)

2.2.5 Economic importance of watermelon

According to Adeoye *et al*. (2007) watermelon is the most preferred among five other exotic vegetables examined in Ibadan Metropolis of Oyo State, Nigeria. Watermelon is utilized for the production of juices, nectars and fruit cocktails (Wani *et al.,* 2008). The watermelon fruit is 93% water, with small amounts of protein, fat, minerals, and vitamins. However, the major nutritional components of the fruit are carbohydrates, vitamin A, and lycopene, an ant carcinogenic compound found in red flesh watermelon (Majid, 2011).

Watermelon rind contains an important natural compound called citrulline, an amino acid that the human body makes from food. One of the key roles of citrulline is to create another amino acid, argenine that plays an important role in wound healing, detoxification reactions, immune functions, and promoting the secretion of several hormones including insulin and growth hormone (Flynn *et al.*, 2002). According to Badifu (1993) and Loukou *et al*. (2007) seeds of *Citrullus* spp are important for supply of oil and protein.

2.2.6 Constraints to watermelon production

Watermelons are sensitive to cold temperatures and even a mild frost can severely damage the crop. Soil borne diseases are among the major constraints in watermelons production. Production of resistant varieties for the diseases increases the cost of production. Traka–Mavrona *et al.* (2000) pointed out that because of the prevalence of soil–borne diseases; almost all watermelons are grafted on to disease–resistant rootstocks. Inadequate organic matter in many soils is another constraint in watermelon production. Aguyoh *et al.* (2010) reported that Watermelon production level in Kenya has been constrained by the low soil fertility, especially low soil N and organic matter.

2.3 Pumpkin

Pumpkin (*Cucurbita* spp.) is one of the crops which belong to the family, Cucurbitaceae (Blessing *et al*., 2011). According to Yadegari *et al.* (2011) the crop has 5 domestic species and 10 wild species, the most important species are *Cucurbita muschata, Cucurbita pepo* and *Cucurbita maxima* with common names Squash, Pumpkin and Guard, respectively.

2.3.1 Botany of pumpkin

Pumpkins have strong round stems with large roundish to kidney–shaped leaves that are slightly scalloped. The fruit stalk is round and fleshy when mature and the skin is hard. *Cucurbita moschata* has monoecious, self–compatible unisexual flowers, which are actinomorphic with pentamerous perianths (Agbagwa *et al.*, 2007).

2.3.2 Origin and distribution of pumpkin

The Cucurbita genus is of American origin (Balkaya *et al.*, 2009). Hernandez *et al.* (2005) pointed out that phenotypic diversity within populations of Cucurbita is high and includes variation in shape, size and colour of fruits. Pumpkins are distributed in many agricultural regions worldwide. According to Balkaya *et al.* (2009), *C. maxima* are the most diverse *Cucurbita* spp. after *C. pepo* and are found throughout tropical and temperate regions.

2.3.3 Pumpkin production

According to Balkaya *et al.* (2009) *Cucurbita* spp. is collectively ranked among the 10 leading vegetable crops worldwide. Three species namely *C. pepo*, *C. moschata* and *C. maxima* are cultivated worldwide and have high production yields (Phillips *et al*., 2005). The top five pumpkin producers in the world are as presented in Table 3.

Table 3: Top five world pumpkin producers 2010

Country	Production in metric tone
China	6 359 623
India	3 500 000
Russian Federation	953 840
United States	786 980
Egypt	651 859
Total	**12 222 302**

Source: FAO (2010)

2.3.4 Economic importance of pumpkin

According to Robinson and Decker–Walters (1997) pumpkins have much fatty acids, proteins, Se and Zn. Seeds have many essential oil and protein. Horvath and Bedo (1988) pointed out that non–saturated oils of pumpkin seeds (linoleic acid, β sytosterol, vitamin E,) are used in making many medicinal drugs. Pumpkins are also rich in vitamin C, vitamin E, lycopene and dietary fiber (Pratt and Matthews, 2003).

2.3.5 Constraints to pumkin production

Foliar diseases are the major problem of pumpkins in humid weather (Napier, 2009). Weather condition is another constraint of pumpkin production. Fruit yield of pumpkins is substantially affected by prevailing climatic conditions such as strong winter and high temperature (Wien, 1997; Hassan, 2004).

2.4 Fruit Fly Species Infesting Cucurbits

There are a number of tephritid fruit flies that attack cucurbit fruits causing variable levels of damage, in different agro-climatic regions of the world. White and Elson–Harris (1992) listed 11 fruit fly species of Cucurbitaceae. The list is as presented in Table 4.

Table 4: List of fruit flies species attacking cucurbits

S/N	Pest species
1	*Dacus bivittatus* (Bigot)
2	*Dacus ciliatus* (Loew)
3	*Dacus punctatifrons* (Karsch)
4	*Bactrocera cucurbitae* (Coquillett)
5	*Dacus (callantra) solomonensis* (Malloch)
6	*Dacus smieroides* (Walker)
7	*Dacus vertebratus* (Bezzi)
8	*Dacus demerezi* (Bezzi)
9	*Dacus teifairaea* (Bezzi)
10	*Dacus frontalis* (Becker)
11	*Dacus lounsburyii* (Coquillett)

According to White and Elson–Harris (1992) *B. cucurbitae* is a pest of major significance. It causes losses in many cucurbitaceous crop like melons, gourds and cucumber that are important in the diet of people.

2.5 Fruit Flies (Diptera:Tephritidae) and their Life Cycle

The pests undergo complete holometabolous consisting of four stages which are egg, larva, pupa and adult. The egg is pure white, about two millimeters long, elliptical, nearly flat on the ventral surface, more convex on the dorsal (Weems *et al.,* 2012). The flies lay eggs on mature green and ripening fruit. Some species may lay eggs in unripe fruit lets. The larvae are whitish maggots. They feed on the fruit flesh causing the fruit to rot. After 4 to 17 days the maggots leave the fruit, making holes in the skin, and drop to pupate in the soil. Adult emergence occurs after several days of pupa stage.

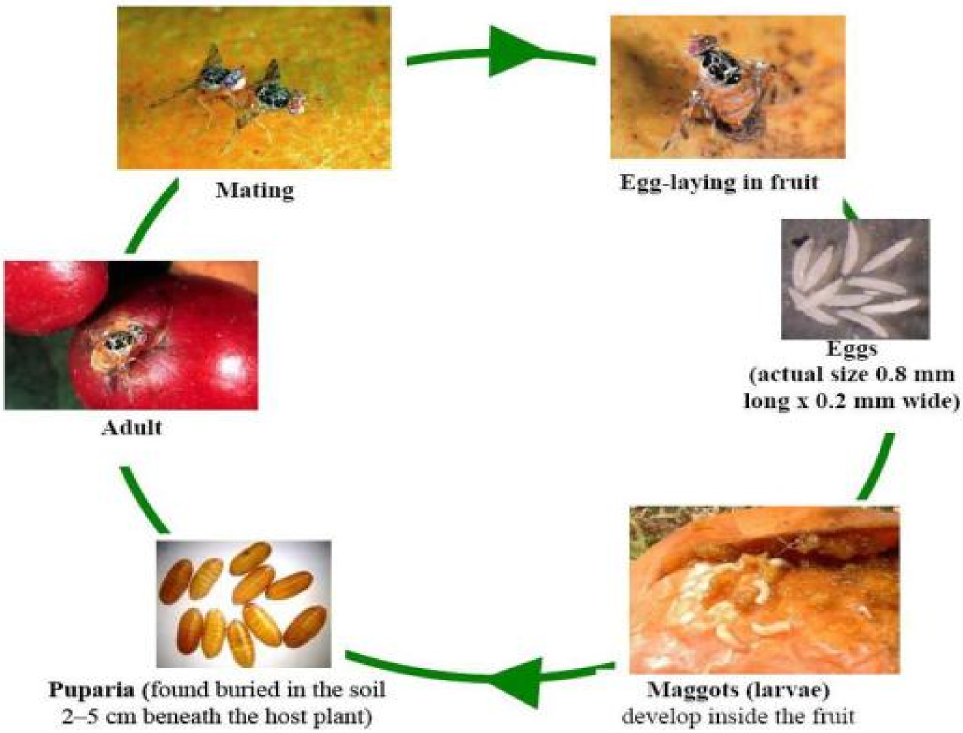

Plate 1: The life cycle of fruit fly

Source: Infonet–biovision (2010)

2.6 Cucurbit Fruit Flies in Tanzania

Cucurbit fruit flies are all fly species that infest cucurbitaceae fruits. Major fruit fly species infesting cucurbits in Morogoro Tanzania are *B. cucurbitae, D. bivittatus, D. frontalis* and *D. ciliatus* (Mwatawala *et al.*, 2010).

2.6.1 *Bactrocera cucurbitae*

This is a very serious pest of cucurbit crops (White and Elson–Harris, 1992). The fly specie belongs to subgenus Zeugodacus Hendel, a group whose members have a strong preference for attacking Cucurbitaceae (White and Elson–Harris, 1992). The melon fly, is a pest of major significance. It has been recorded from over 125 plants, including members of families other than cucurbitaceae (Weems, 1964).

Plate *2*: *Bactocera cucurbitae*

Source: Wikipedia (2012)

2.6.1.1 Distribution of *B. cucurbitae*

The *B. cucurbitae* is distributed widely in temperate, tropical, and sub–tropical regions of the world (Dhillon *et al.*, 2005). According to Weems and Heppner (2010) the pest is well distributed over most of India which is considered to be its native home and throughout most of South East Asia. CABI (2005) reported the distribution of this pest as follows:

Africa: Cameroon, Cote d'Ivoire, Egypt, Gambia, Kenya, Mali, Mauritius, Reunion, Seychelles, Somalia, Tanzania;

Asia: Afghanistan, Bangladesh, Brunai, Cambodia, China (numerous provinces), Christmas Island, East Timor, India (numerous states), Indonesia (numerous islands), Iran, Laos, Malaysia, Myanmar, Nepal, Oman, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, United Arab Emirates, Vietnam and

North America: United States: established in Hawaii, periodic interceptions in other states

Oceania: Guam, Kirbali, Nauru, Northern Mariana Islands, Papua New Guinea, Solomon Islands.

The melon fruit fly remains active throughout the year on one or the other host. During the severe winter months, they hide and huddle together under dried leaves of bushes and trees (Dhillon *et al.*, 2005). During the hot and dry season, the flies take shelter under humid and shady places and feed on honeydew of aphids infesting the fruit trees. Bhatia and Mahto (1969) reported that the life cycle is completed in 36.3, 23.6, 11.2, and 12.5 days at 15, 20, 27.5, and 30°C, respectively.

2.6.1.2 Eggs

The egg is pure white, about two millimeters long, elliptical, nearly flat on the ventral surface, more convex on the dorsal (Weems, 2012). Samalo *et al.* (1991) found that egg viability, larval and pupal survival on cucumber are 91.7, 86.3, and 81.4%, respectively; while on pumpkin were 85.4, 80.9, and 73.0%, respectively, at 27 ± 1.

2.6.1.3 Larvae, pupae and adults emergence

The larval period lasts for 3 to 21 days (Hollingsworth *et al.,* 1997) depending on temperature and host. On different cucurbit species, the larval period varies from 3 to 6 days (Koul and Bhagat, 1994; Gupta and Verma, 1995). According to Huang and Chi (2011) pupation rate of *B. cucurbitae* at 25°C are 79%, 64% and 70% on cucumber sponge gourd and carrot medium respectively. Liu and Ye (2009) reported that percentage of adults of *Bactrocera correcta* (Bezzi) emerging from a batch of 100 pupae peaked at 97.25% at 30°C. The full–grown larvae come out of the fruit by making one or two exit holes for pupation in the soil. The larvae pupate in the soil at a depth of 0.5 to 15 cm (Dhillon *et al.,* 2005). Pandey and Misra (1999) reported that the depth up to which the larvae move in the soil for pupation, and survival depend on soil texture and moisture. Depending on temperature and the host, the pupa period may vary from 7 to 13 days (Hollingswoth *et al.,* 1997). According to Koul and Bhagat (1994) the pupal period varies from 6.5 to 21.8 days on bottle gourd. Jiang *et al.* (2006) observed a longer larval stage (12.09 days) and a shorter pupal stage (7.5 days) on cucumber at 30°C. Vayssi`eres *et al.* (2008) reported a total development time of *B. cucurbitae* on cucumber as 17.2 and 13.2 days at 25 and 30°C, respectively. Generally total pre-adult duration of *B. cucurbitae* ranged from 14 to 20 days at 24 to 30°C (Huang and Chi, 2011).

2.6.1.4 Host range

White and Elson–Harris (1992) recorded *B. cucurbitae* from the following species of cucurbitaceae: angled luffa (*Luffa acutangula)* balsam–apple (*Momordica* *balsamina),* Bitter gourd (*M. charantia*), Colocynth (*Cintrullus colocynthis),* Cucumber (*C. sativus*) pumpkins (*C. maxima* and *C. pepo*), water melon (*C. lanatus*), wax gourd (*B. hispida*) and white flowered gourd (*Lagenaria siceraria*).

2.6.2 *Dacus bivittatus*

This species has also been known as *Dacus bipartitus* Graham, *D. cucurmarius* Sack, *D. pectoralis* Walker, *D. rubiginosus* Hendel, *Leptoxys Bivittatus* Bigot and *Tridacus pectoralis* (Walker) (White and Elson–Harris, 1992).

Plate 3: *Dacus bivittatus*

Source: Copeland (2005)

2.6.2.1 Distribution and life history

The pest is well distributed in Africa*:* Angora, Cameroun, Kenya, Malawi, Mozambique, Nigeria, Sierra Leone, South Africa, Tanzania, Uganda, Zaire, Zimbabwe (White and Elson–Harris, 1992).

2.6.2.2 Host range

A wide range of cucurbits is attacked ranging from cucumber, melon and various types of squash to pumpkins. The smaller species tend to attack smaller fruits. Munro (1984) pointed out that many species of Cucurbitaceae, e.g. wild *Momordica* and *Peponium spp* are hosts of this fly species.

2.6.3 *Dacus frontalis*

This is a pest of cucurbit (Hancock, 1989). It has also been known as *Dacus ciliatus* var duplex (Munro), *Dacus ciliatus* form *frontalis* (Becker) and *Dacus scopatus* (Munro) (White and Elson–Harris, 1992).

2.6.3.1 Distribution of *D. frontalis*

According to White and Elson–Harris (1992) the pest is distributed in

Africa: Egypt, Kenya, South Africa, South West Africa, Sudan, Tanzania and Zimbabwe.

Atlantic Ocean Islands: Cape Verde Islands.

Middle East: Saudi Arabia, Yemen Arab Republic.

Plate 4: ***Dacus frontalis***

Source: Copeland (2005)

2.6.3.2 Description and life history

Dacus frontalis is a predominantly orange species; with facial spots, two scutellar setae, a yellow stripe covering most of anatergite and katatergite, only mid femur darkened in apical half, and wing with a costal band that is expanded apically to form an apical spot (White and Elson–Harris, 1992).

2.6.3.3 Host range

Steffens (1983) pointed out that in the Cape Verde Islands the major hosts are Cucumber (*C. sativus*), Pumpkins (*C. pepo*), Sweet melon (*C. melo*), Water melon (*C. lanatus*) and colocynth (*Citrullus colocynthis*).

2.6.4 *Dacus ciliatus*

This species has also been known as *Dacus bipartitus* Graham, *D. cucurmarius* Sack, *D. pectoralis* Walker, *D. rubiginosus* Hendel, *Leptoxys Bivittatus* Bigot and *Tridacus pectoralis* (Walker) (White and Elson–Harris, 1992). It is the pest of cucurbit crops particularly in moist forest area (Hancock, 1989). The pest is native of Africa and widely distributed in different countries of Europe, Africa, Middle East and the Indian sub–continent (Srivatstava and Butan, 2009). According to Srivatstava and Butani (2009) the insect is a major pest of melons causing severe losses during February to April in India. Overwintering takes place in pupal stage (Pruthi and Batra, 1960).

Plate *5*: *Dacus ciliatus*

Source: Copeland (2005)

2.6.4.1 Distribution *D. ciliatus*

According to Weems (2012) *Dacus ciliatus* was reported first in India in 1914 and was collected from Ombo, Upper–Egypt, in February 1953. It occurs throughout most of eastern, southern, and central Africa, Malagasy Republic (Madagascar), Mauritius and Reunion Islands, the Arabian Peninsula, Pakistan, India, Bangladesh and Sri Lanka (White and Elson–Harris, 1992).

2.6.4.2 Host plants and damage

Many species of cucurbitaceae e.g. *Momordica spp* are host plants of this pest (Matanmi, 1975; Munro, 1984). According to Shaheen *et al.* (1973) in Egypt, wild growing colocynth is believed to be main reservoir host from which crops become infested.

2.6.4.3 The life cycle of *D. ciliatus*

According to Cherian and Sundaram (1939) egg, maggot and pupal stages last for one to two, three to six and 8 to 10 days respectively. Total life cycle takes 15 to 17 days in October and there six generation in a year in South India while in North India where there is distinct winter season there are only 4 to 5 generations in a year (Srivastava and Butani, 2009). Generally life cycle duration depend much on temperature and host.

2.7 Damage Inflicted by Fruit Flies in Cucurbits

Cucurbit fruit flies attack different types of cucurbits causing variable levels of damage in different agro–climatic regions of the world. Kapoor (2004) pointed out that fruit and vegetable worth 30 000 rupees (approximately 662 million USD in 2004) are damaged by fruit flies every year in India. The cucurbit fruit fly causes significant damage in cucurbits preferably in young and immature stages. Sapkota *et al.* (2010) pointed out that cucurbit fruit fly causes more damage in immature squash fruits than in harvestable stage. Weems and Heppner (2004) reported that adult females preferred unopened flowers and young fruits for egg laying.

2.8 Incidence and Infestation of Fruit Flies in Cucurbits

Studies on cucurbit flies infestation in Morogoro were done by Mwatawala *et al.* (2010) and observed that *B. cucurbitae* is the sole fly pest of luffa and the main infester of the commercial hosts (cucumber and melon), as well as wild host, Momordica cf trifoliate. Vargas *et al.* (1984) indicated *B. cucurbitae* as a K–selected species. According to Duyck *et al.* (2004, 2007) K–selected fruit fly species appear to be better invaders, which could explain the high incidence of *B. cucurbitae* in both cucumber stages over the two pest species. Peak populations of *B. cucurbitae* were recorded during the dry period, when temperatures and relative humidity were also low (Mwatawala *et al.*, 2010). According to Mohsen and Russell (2003) the second significant host in Thailand was cucumber (*C. sativus*) harboring 33.2 *B. cucurbitae* / kg of fruit. Maximum fruit fly emergence of 494.64/ kg fruit was on bitter gourd in October, 2002 followed by cucumber 431.97 in November 2002, pickling cucumber 307.51 in October 2002 and ridge gourd 210.74 in October 2003 (Kumar *et al.*, 2006). Focusing in Tanzania, both wild and commercial fruits, the infestation rate varied between 37 and 157 flies/kg fruits while the incidence ratios was 0.15 and 0.72 (Mwatawala *et al.*, 2010).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site

Studies were conducted under laboratory conditions from November 2011 to August 2012 at Sokoine University of Agriculture (SUA) located at latitude 6°50' South and longitude 37°39' East and elevation of about 525 m. The experiments namely comparison of incidences and infestation rates of cucurbit infesters, establishment of duration and determination of survival rates of *B. cucurbitae* developmental stages were carried out as described hereunder.

3.2 Comparison of Incidences of Cucurbit Infesters in Cucumber

Cucumber variety Ashley was grown in crop museum of SUA between June and August 2012 for fruit sampling. Standard agronomic practices for the crop were followed. Twenty fruits each incubated in a separate container formed a sample for both immature (Six weeks after planting) and harvestable stage (Eight weeks after planting), replicated three times. Harvestable cucumber fruits were determined by using cucumber harvesting indices i.e by observing presence of blunt spines and dark green epidermis (Olson *et al.*, 2011). Fruit samples were put in plastic bags suspended in boxes in order to avoid damage as described by Mwatawala *et al.* (2010). Thereafter, they were transported to the rearing unit at horticulture unit SUA, labeled and registered with unique identifiers according to the protocol described by Copeland *et al.* (2002). All fruits were weighed before keeping them in individual rearing boxes and provided with an appropriate medium for pupation. The positive samples (samples with emerged flies) were recorded. Emerged adult flies were removed from rearing cages by an aspirator (pooter) and preserved in vials containing 70% alcohol for preservation. Then flies were identified to species level using keys. Three cucurbit fruit fly species were targeted, namely *B. cucurbitae, D. bivittatus* and *D. frontalis*. First, incidences of a fruit fly species in a sample of twenty fruits were averaged. Then incidence of each fruit fly species in each cucumber fruit stage was determined by dividing number of positive samples to the total number of samples in the stage. Split plot experiment was used to compare incidences cucurbit fruit fly species in two cucumber fruit stages. The sources of variation were cucumber fruit stages and cucurbit fruit fly species. The main factor was cucumber fruit stage and the sub factor was fruit fly species. Data on incidences of cucurbit fruit fly species in cucumber fruit stages were log transformed to improve normality before subjecting in a two way analysis of variance (ANOVA) followed by LSD means separation test to identify significant effect.

3.3 Comparison of Infestation Rates of Cucurbit Infesters in Cucumber

The procedures for cucumber fruit sampling and experimental setting up to fruit fly species identification described in section 3.2 were followed. Initially average infestation rates of a fruit fly species in a sample of twenty fruits were computed. Infestation rates were obtained by dividing number of emerged fruit flies by weight of fruits. Split plot experiment was used to compare infestation rates of three fruit fly species in two cucumber fruit stages. The sources of variation were cucumber fruit stages and fruit fly species. The main factor was cucumber fruit stage and the sub factor was fruit fly species. Infestation rates of *B. cucurbitae*, *D. bivittatus* and *D.*

frontalis were subjected in a two way analysis of variance (ANOVA) followed by LSD means separation test to identify significant effect.

3.4 Establishment of duration of *B. cucurbitae* developmental stages

The experiment was conducted in Basic and Applied entomology laboratory of SUA to investigate developmental time of immature stages of *B. cucurbitae.* The colonies of *B. cucurbitae,* were established from infested fruits of *C. sativus, C. pepo* and *C. lanatus* for cohorts (eggs, larvae and pupae) extraction used in the experiment. Adults flies were grouped in a 30 pairs and kept in individual plastic containers (30×15×10 cm) covered with fine mesh for ventilation. They were fed simultaneously with enzymatic yeast hydrolysate (ICN Biomedical) and sucrose in a ratio of 1:3 and water on pumice granules in different plastic container. The containers were kept at 20, 25 and 30°C temperature regimes with 75 ± 10% Relative humidity and 12:12 (L:D) –h photoperiod in the environmental chamber. Thin slices of *C. sativus, C. pepo* and *C. lanatus* were prepared and placed in each container for egg laying. The hosts at immature stage for slice preparation were obtained from the field where they have been grown throughout the study period. Eggs, lavae and pupae were extracted following procedures described by Vayssieres *et al.* (2008). The colonies of cucurbit fruit fly species were maintained for cohort extraction throughout the study. A factorial experiment was used to compare developmental time of immature stages of *B. cucurbitae* in three cucurbitaceous hosts at three temperature regimes as described hereunder.

3.4.1 Duration of *B. cucurbitae* eggs

The duration of egg stage was established by placing batches of 100 eggs collected randomly from slices (Plate 6) of *C. sativus*, *C. pepo* and *C. lanatus* with a camel hair brush and placed on the moist filter paper in the petri dish at a temperature of 20, 25, and 30 ± 1.0°C (Vayssieres *et al*., 2008). Eggs were observed twice a day under a microscope. Time taken to 50% eggs hatch was recorded. The experiment was replicated three times.

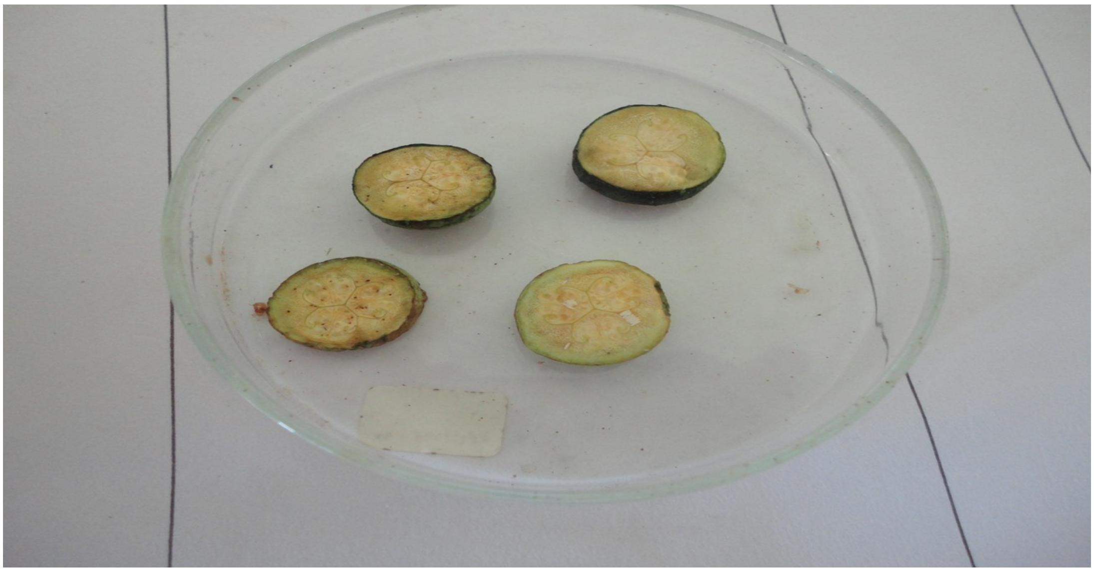

Plate 6: Slices of premature cucurbit fruit with *B. cucurbitae* eggs

3.4.2 Larva developmental time of *B. cucurbitae*

Batches of 50 newly emerged larvae from specific cucurbit host (Plate 7) were placed onto slices of *C. sativus, C. pepo* and *C. lanatus*. Each slice was placed in an individual petri dish. The petri dishes were simultaneously placed into environmental chamber set at one temperature regime at a time. The exercise was repeated for each of the three tested temperature of 20, 25 and 30°C. Replicates were three petri dishes with each slice exposed to each temperature regime. Time required for 50% larvae to pupate was recorded. Pupae were collected by sifting the sand, counted and carefully cleaned (Vayssieres *et al*., 2008) and put on a petri dish as presented in Plate 8.

Plate 7: Larvae of *B. cucurbitae* feeding in cucurbit host

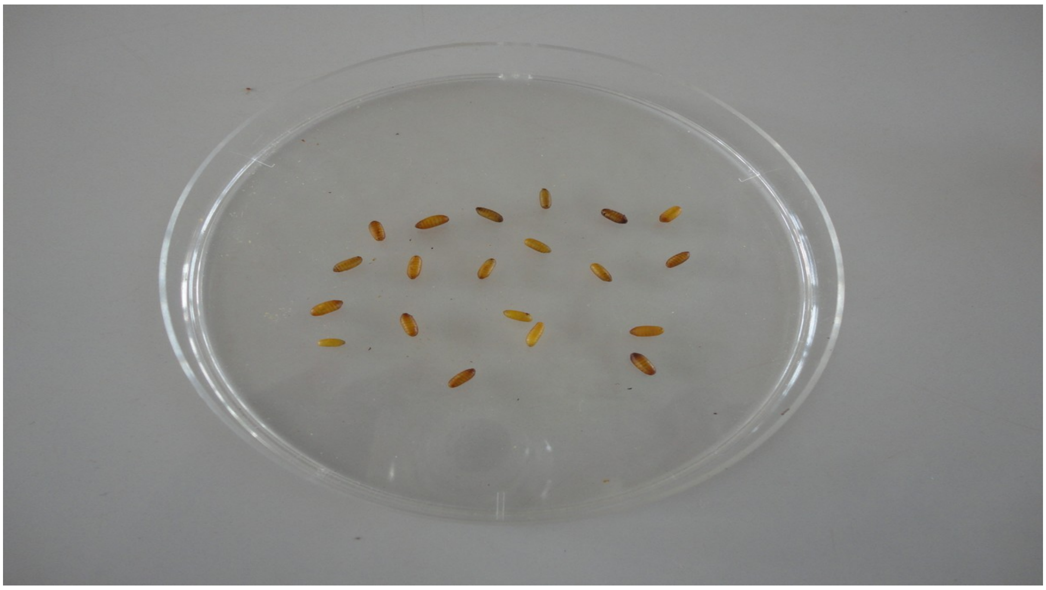

Plate 8: Pupae of *B. cucurbitae*

3.4.3 Pupae developmental time of *B. cucurbitae*

Batches of 30 pupae from each of fruit species were introduced into a petri dish containing wet sand. The petri dishes were simultaneously subjected to one temperature regime. Fresh sets of petri dishes were introduced into each of the three tested temperature regimes of 20, 25 and 30°C. Three replicates were maintained for three petri dishes each with pupae originating from a fruit species exposed to each of the temperature regime at a time. At the end of the pupal stage, the time needed for 50% of pupae to emerge into adult flies were recorded. The number of newly emerged adults was recorded twice a day.

3.4.4 Total developmental time of *B. cucurbitae* from egg to adult

The developmental time from egg to adult of *B. cucurbitae* was established by recording time taken from when the eggs placed onto the slices of *C. sativus, C. pepo* and *C. lanatus* in the petri dishes to emergence of adult flies. The exercise was repeated for each of the three temperature regimes of 20, 25 and 30°C in the environmental chamber. Replicates were three petri dishes with cucurbitaceous slices exposed in each temperature regime at a time. Data on duration were subjected in a two way Analysis of variance (ANOVA) followed by LSD means separation test to identify significant effect.

3.5 Determination of *B. cucurbitae* developmental survival

Cohorts of eggs, larvae and pupae for the experiment were extracted following procedures described in section 3.4.

3.5.1 Determination of *B. cucurbitae* egg survival

The eggs hatchability rate was determined by placing batches of 100 eggs from each cucurbitaceous host onto the moist filter paper in the Petri dish at a temperature of 20, 25, and 30 ± 1.0°C. Observations on number of eggs hatched were made twice a day under a microscope. Eggs survival rate was determined by relating number of eggs hatched and total number of eggs placed onto filter paper. The sources of variation were cucurbitaceous hosts and temperature regimes. Replicates were three petri dishes with eggs originating from fruit species on moist filter paper exposed to each temperature regime.

3.5.2 Determination of *B. cucurbitae* larvae survival

Pupation rate of *B. cucurbitae* were determined by placing batches of 100 newly emerged larvae onto slices of *C. sativus, C. pepo* and *C. lanatus*. Each slice was placed in an individual petri dish. The petri dishes were simultaneously placed into environmental chamber set at one temperature regime at a time. The exercise was repeated for each of the three tested temperature of 20, 25 and 30°C. Larva survival rate was determined by relating number of larvae succeeded to pupate and those transferred to petri dish containing cucurbitaceous host. Replicates were three petri dishes with each cucurbitaceous slice exposed to each temperature regime.

3.5.3 Determination of *B. cucurbitae* pupae survival

Emergence rate of *B. cucurbitae* were determined by placing batches of 100 pupae from each of fruit species into a petri dish containing wet sand. The petri dishes were simultaneously subjected to one temperature regime at a time. Fresh sets of petri dishes were used for each of the three tested temperature regimes of 20, 25 and 30°C. Pupa survival rate was determined by relating number of pupae succeeded to emerge into adult flies to those introduced into petri dishes. Replicates were three petri dishes with pupae originating from fruit species exposed to each temperature regime. Data on survival rates (%) were log transformed to improve normality then subjected in a two way Analysis of variance (ANOVA) followed by LSD means separation test to identify significant effect.

3.6 Data Analysis

Data collected were analyzed using GENSTAT (VSN International Ltd, UK). All data from the experiments subjected to analysis of variance (ANOVA) were under the following statistical models:

3.6.1 Statistical model for comparison of incidences and infestation rates of cucurbit infesters in cucumber

$$Yijk = \mu + \alpha i + \beta j + \alpha\beta ij + \gamma ki + \varepsilon ijk \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Whereas:

$Yijk$ = Response

μ = General mean

αi = Main effect of cucumber fruit stages

βj = Sub effect of cucurbit fruit fly species

$\alpha\beta ij$ = Interaction between main effect of cucumber fruit stages and sub effect of cucurbit fruit fly species

γki = Main effect of cucumber fruit stages error

εijk = Error term for each observation

3.6.2 Statistical model for determination of developmental time and survival of immature *B. cucurbitae* stages

Y_{ijl} = μ+α_i + $\beta_{j+}$$Y_{ij+}$ ε_{il}………………………………….. (2)

where;

Y_{ijl} = Response

μ= General mean

αi = Effect of cucurbit fruit species

β_j = Effect of temperatures regimes

Y_{ij} = Interaction effect between cucurbit fruit species and temperature regimes

εil = Error term for each observation.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Weather Condition During the Study Period

The minimum and maximum average temperature during the growth period of cucurbit crops ranged from 19.96 to 30.9ºC. The average relative humidity was 61.6%. Total rainfall was 770 mm. The average maximum temperature, relative humidity and total rainfall (Appendix 1) were suitable for the cucurbits growth.

4.2 Incidence of Cucurbit Infesting Fruit Flies in Cucumber Fruit Stages

Incidences of cucurbit fruit flies in cucumber fruit stages varied significantly among fruit fly species (F= 28.92; df = 2; P = 0.001) but not between cucumber fruit stages (F= 12.92; df = 1; P = 0.055). Focusing on cucurbit fruit fly species the highest incidence was observed in immature cucumber fruits with *B. cucurbitae* while the lowest incidence was observed in mature cucumber fruits with *D. frontalis* (Fig. 1).

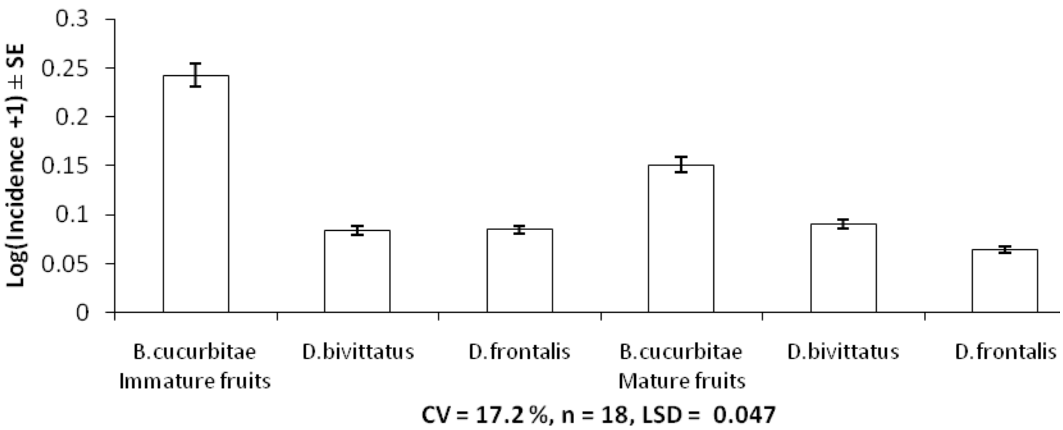

Figure 1: Incidences of three cucurbits infesting fruit fly species in cucumber fruit stages

Among the three fruit fly species infesting cucumber *B. cucurbitae,* had high incidence compared to other two in both immature and mature cucumber fruits. Vargas *et al.* (1984) indicated *B. cucurbitae* as a K–selected species. According to Duyck *et al.* (2004, 2007) K–selected fruit fly species appear to be better invaders; this could explain the high incidences of *B. cucurbitae* observed in both cucumber fruit stages over the two pest species. The incidences of cucurbit fruit flies in cucumber increased with increase in level of immaturity from mature to immature fruit stage (Fig. 1) although statistically were similar. Generally for all selected cucurbit fruit flies species the incidences in cucumber were lower in harvestable than immature stages.

Lower incidences in harvestable stage compared to immature stage could have been caused by hard epidermis of harvestable cucumber fruits reducing the ability of oviposition by the pests. According to Weems and Heppner (2004) adult female fruit flies preferred unopened flowers and young fruits for egg laying. Furthermore, Sapkota *et al.* (2010) reported that cucurbit fruit fly (*B. cucurbitae*) causes more damage on immature squash fruits than in harvestable stage. Generally, the females prefer to lay eggs in soft tender fruit tissues by piercing them with the ovipositor (Dhillon *et al.*, 2005). The maximum incidence (0.75) of *B. cucurbitae* at immature cucumber fruit stage was slightly higher than 73.83% and 0.72 reported by Kumar *et al.* (2006) and Mwatawala *et al.* (2010) respectively.

4.3 Infestation Rates of Cucurbit Infesting Fruit Fly species in Cucumber Fruit Stages

Results showed highly significant differences on infestation rates among cucurbit fruit fly species (F = 135.73; df = 2; P = 0.001) and between cucumber fruit stages (F = 110.24; df = 1; P = 0.01).The highest infestation rate (120 flies/Kg fruit) was recorded in immature cucumber fruit infested by *B. cucurbitae* while the lowest infestation rate was recorded in immature cucumber fruits (5 flies/Kg fruit) infested by *D. frontalis* (Fig. 2).

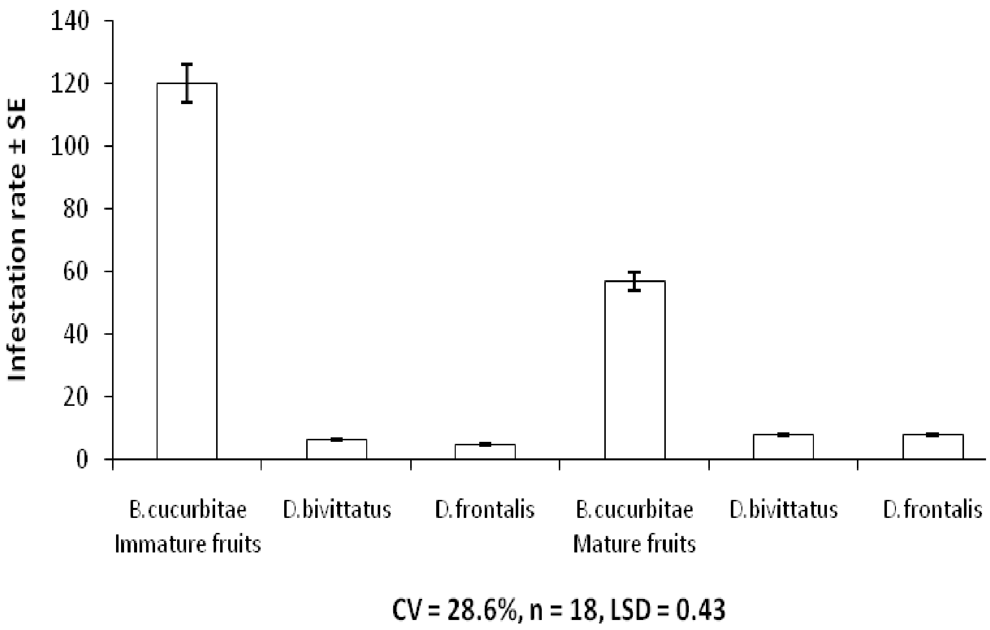

Figure 2: Infestation rates of three cucurbits infesting fruit fly species in immature and mature cucumber fruit

Of the three fruit flies species, *B. cucurbitae* had high infestation rate followed by *D. bivittatus* and *D. frontalis.* There was no significant difference in infestation rates between *D. frontalis* and *D. bivittatus* in both immature and harvestable stages of cucumber fruits (Fig. 2). The infestation rates (120 flies/kg fruits) of *B. cucurbitae* in immature and (57 flies/kg fruits) in harvestable cucumber fruits were higher than 32.2 flies/kg cucumber fruits reported by Mohsen and Russell (2003). However, the rates were lower than 431.97 flies /kg cucumber fruits pointed out by Kumar *et al.* (2006). According to Mwatawala *et al.* (2010) who collected both wild and commercial hosts, the infestation rate of *B. cucurbitae* varied between 37 and 157 flies/kg fruits. High infestation rate by *B. cucurbitae* in both two cucumber fruit stages compared to *D. bivittatus* and *D. frontalis* could have been attributed by dry condition during cucumber growth period (Appendix 1) and high competitive ability of the pest. According to Mwatawala *et al.* (2010) peak populations of *B. cucurbitae* were recorded during the dry period. Furthermore many field records show that *Bactrocera* spp are best adapted to exploit and to compete with other species in the same ecological niche (Vayssieres *et al*., 2008).

4.4 Establishment of *B. cucurbitae* Immature Stages Duration

4.4.1 Embryonic developmental time of *B. cucurbitae*

The egg incubation period varied significantly among temperature regimes (F = 100.7; df = 2; P = 0.001) but not among hosts (F = 1.02; df = 2; P = 0.381) or interaction between hosts and temperatures regimes (F = 1.09; df = 2; P = 0.391). The longest egg duration (2.073 days) was recorded in *C. sativus* at 20ºC while the shortest egg duration (0.993 days) was recorded in *C. lanatus at* 30ºC. Average time for egg hatching increased with decrease in temperatures (Fig. 3).

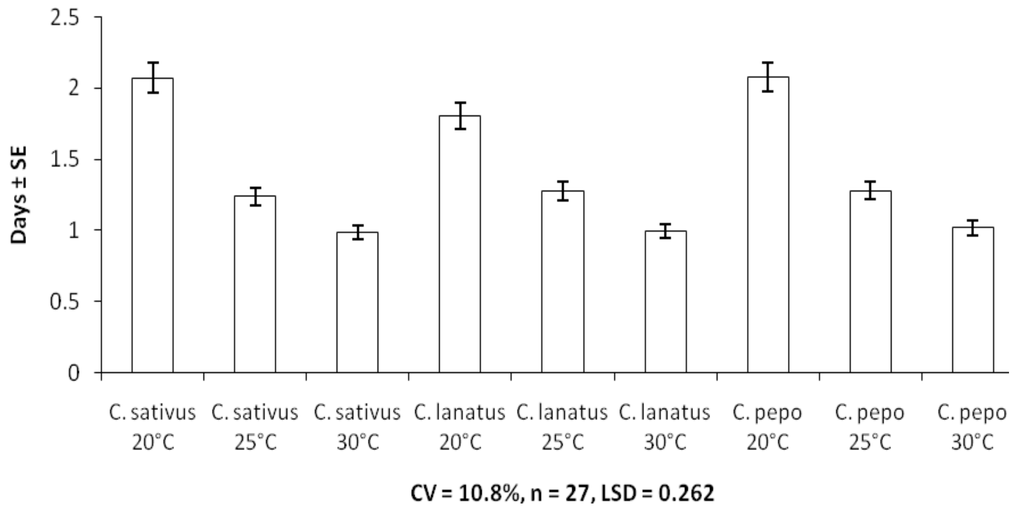

Figure 3: Mean egg incubation period for *B. cucurbitae* in three cucurbit hosts at three temperature regimes

4.4.2 Larval developmental time of *B. cucurbitae*

The larval developmental time (Fig. 4) varied significantly among temperature regimes (F = 63.43; df = 2; P = 0.001) but not among hosts (F = 1.2; df = 2; P = 0.319) or interactions between host and temperature regime (F = 1.41; df = 2; P = 0.270). The longest larval duration (6.67 days) was recorded in *C. sativus* at 20ºC while the shortest larval duration (3.63 days) was recorded in *C. sativus* at 30ºC. At larval and pupal stages, the trend was similar to egg stage with shortest mean developmental time at 30°C in all cucurbitaceous hosts.

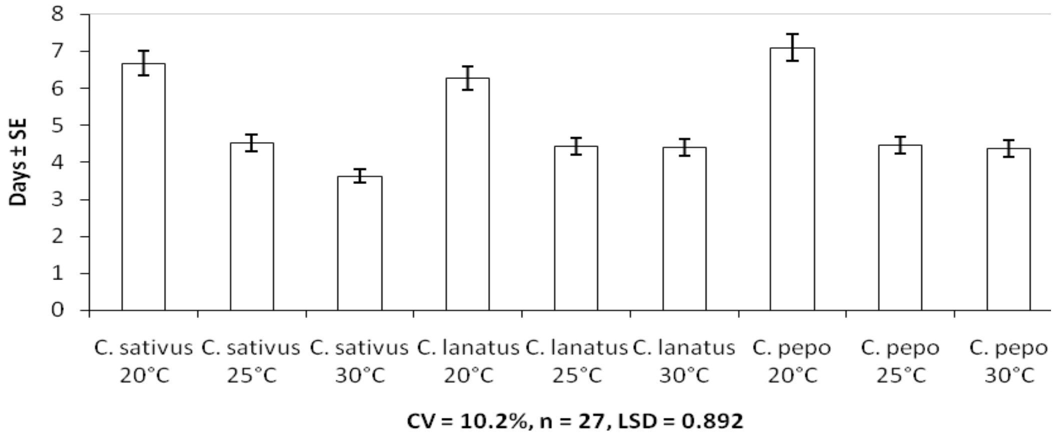

Figure 4: Mean developmental time (days) of larval of *B. cucurbitae* in three hosts at three temperature regimes

4.4.3 Pupal developmental time of *B. cucurbitae*

The pupal duration (Fig. 5) also varied significantly with temperature regimes ($F = 223.42$; $df = 2$; $P = 0.001$). However no significant differences were observed among hosts ($F = 1.04$; $df = 2$; $P = 0.372$) or interactions between host and temperature ($F = 2.51$; $df = 2$; $P = 0.078$). The longest pupal duration (16.23 days) was recorded in *C. sativus* at 20ºC while the shortest duration (8.57 days) was recorded in the same host at 30ºC. Average time for pupal duration decreased with increase in temperature.

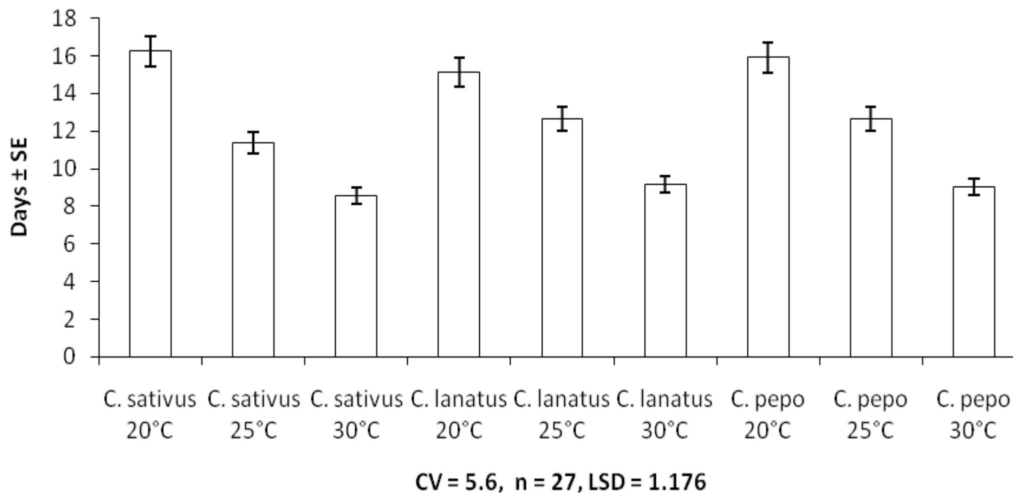

Figure 5: Mean developmental time (days) of pupal of *B. cucurbitae* in three hosts at three temperature regimes

4.4.4 Total development of *B. cucurbitae* from egg to adult

Total developmental time (days) from egg to adult varied significantly among temperature regimes (F= 135.25; df = 2; P = 0.001) but not among hosts (F= 0.96; df = 2; P = 0.403) or interactions between host and temperature (F= 1.64; df = 2; P = 0.208). The longest developmental time (25.1 days) of *B. cucurbitae* was recorded in *C. pepo* at 20ºC while the shortest developmental time (13.2 days) was recorded in *C. sativus* at 30ºC. Total developmental time decreased with increase in temperature in all cucurbit hosts (Fig. 6).

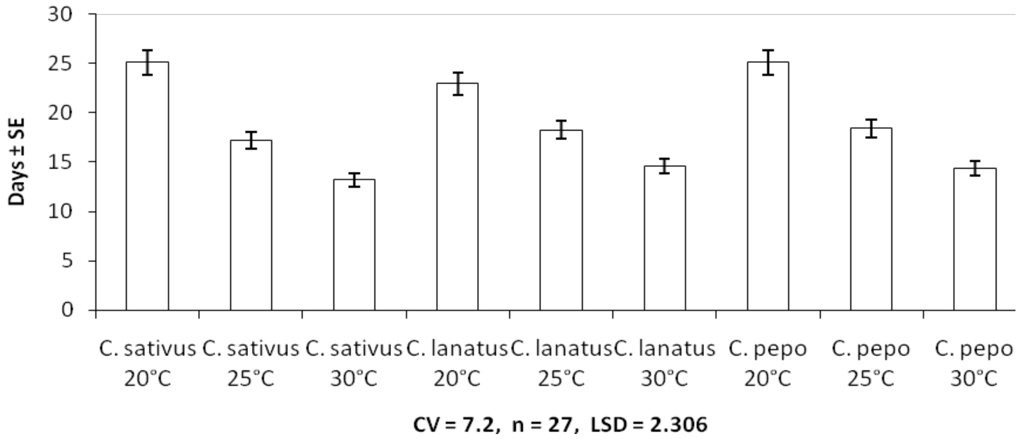

Figure 6: Mean developmental time (days) of *B. cucurbitae* from egg to adult reared in three hosts at three temperature regimes

Duration of immature stages of *B. cucurbitae* varied inversely with temperature regimes. Similar trend was reported by (Vargas *et al.* 2000; Duyck and Quilici 2002). Decreased duration of immature stages of *B. cucurbitae* at high temperatures reveals that *B. cucurbitae* grows and multiplies fast in the area of high temperature (low land areas). According to Ekesi *et al.* (2006) most fruit flies from the genus *Bactrocera* are considered to be low land residents. In Yunan, *B. correcta* only occurs in low–altitude areas under 1 500 m altitude, where the annual average temperatures of these areas are all over 15.8ºC (Liu, 2007).

However, there was no significant difference in duration of immature stages of *B. cucurbitae* among the hosts (*C. sativus, C. lanatus* and *C. pepo*). This could be due to the fact that the hosts are of the same family of Cucurbitaceae. Wagner *et al*. (1984) pointed out that temperature is known to be a very important abiotic factor affecting immature development of insects. Furthermore, Vayssieres *et al.* (2008) reported that there was no significant difference on duration of immature stages of *B. cucurbitae* and *D. ciliattus* with pumpkins, cucumber and squash. Egg incubation periods 23.8, 29.8 and 50.4 hours at 30, 25 and 20°C repectively were almost the same as 23.7, 30, 49.7 hours reportaed by Vayssieres *et al.* (2008).

The lowest duration of *B. cucurbitae* larval stage (3.6 days) at 30°C in cucumber and highest duration (7.1 days) at 20°C in pumpkin fall under the range of 3–21 days reported by Hollingsworth *et al.* (1997). Furthermore, the lowest (8.57 days) and highest (15.90 days) pupal stage duration obseverd in the study are within the range (6.5 to 21.8 days) as reported by Koul and Bhagat (1994) on bottle gourd. Total development time (17.2 days) from egg to adult of the pest at 25°C in cucumber is slightly lower than 17.8 days reported by Huang and Chi (2011). This could have been caused by differences in level of maturity and weight of the hosts used in the experiments.

4.5 Survival Rate of *B. cucurbitae* Immature Stages

4.5.1 Embryonic survival of *B. cucurbitae*

The egg stage survival varied significantly among temperature regimes (F= 167.11; df = 2; P = 0.001) but not among hosts (F= 0.62; df = 2; P = 0.548) or interactions between host and temperature (F= 0.31; df = 2; P = 0.865). The highest embryonic survival rate (97.7%) was observed at 30°C on eggs extracted from C. *sativus* while the lowest survival (76%) was recorded at 20°C on eggs extracted from *C. lanatus*. Embryonic survival increased with increase in temperatures from 20 to 30ºC in all cucurbitaceous hosts (Table 5).

Table 5: Log (% Survival rates) of *B. cucurbitae* eggs in three hosts at three temperature regimes

Temperature °C	Cucurbitaceous hosts		
	C. sativus	*C. lanatus*	*C. pepo*
20	1.881 a	1.881 a	1.882 a
25	1.962 bc	1.951 b	1.960 bc
30	1.990 d	1.980 cd	1.980 cd

CV= 0.6%, n = 27, LSD = 0.021

Log (% Survival rates) followed by the same letter (s) are not significantly different at $P \leq 0.05$ according to LSD means separation test.

4.5.2 Larval survival of *B. cucurbitae*

The larval survival varied significantly among temperature regimes (F = 25.56; df = 2; P = 0.001) but not among hosts (F = 0.01; df = 2; P = 0.989) or interactions between host and temperature (F = 0.07; df = 4; P = 0.990). The highest larvae survival rate (96.8%) was recorded in *C. pepo* at 30ºC while the lowest survival rate (76.9%) was recorded in *C. sativus* at 20ºC. Larval survival of *B.cucurbitae* increased with increase in temperature in all cucurbit hosts (Table 6).

Table 6: Log (% Survival rates) of *B. cucurbitae* larvae in three hosts at three temperature regimes

Temperature °C	Cucurbitaceous hosts		
	C. sativus	*C. lanatus*	*C. pepo*
20	1.888 ab	1.887 a	1.886 a
25	1.908 ab	1.908 ab	1.911 b
30	1.982 c	1.975 c	1.986 c

CV= 0.7%, n = 27, LSD = 0.024

Log (% Survival rates) followed by the same letter (s) are not significantly different at P ≤ 0.05 according to LSD means separation test.

4.5.3 Pupal survival of *B. cucurbitae*

Pupa survival also varied significantly among temperature regimes (F= 210.14; df = 2; P= 0.001) but not among the hosts (F = 0.20; df =2; P = 0.821) or interactions between host and temperature (F = 0.43; df = 4; P = 0.786). The highest pupae survival rate (97.7%) was recorded in *C. pepo* at 30°C while the lowest survival (76.3%) was recorded at 20°C in the same host (Table 7).

Table 7: Log (% Survival rates) of *B. cucurbitae* pupae in three hosts at three temperature regimes

Temperature °C	Cucurbitaceous hosts		
	C. sativus	*C. lanatus*	*C. pepo*
20	1.893 a	1.894 a	1.883 a
25	1.967 b	1.967 b	1.969 b
30	1.989 c	1.990 c	1.990 c

CV= 0.5%, n = 27, LSD = 0.018

Log (% Survival rates) followed by the same letter (s) are not significantly different at P ≤ 0.05 according to LSD means separation test.

Survival rate of *B. cucurbitae* developmental stages increased with increase in temperature from 20°C to 30°C in all tested cucurbitaceous hosts. This indicates that survival of immature stages of *B. cucurbitae* is much favored with increase in ambient temperatures. However, there was no significant difference on survival rate among cucurbitaceous host. This could be due to the fact that the hosts are of the same family of Cucurbitaceae.

Egg survival rate in cucumber at 25°C is similar to (91.7%) recorded by Samalo *et al.* (1991) in the same host at 27 ± 1°C. Larva (80.7%) and pupa (92.68%) survivals in cucumber at 25°C were slightly higher than (79%) and (88%) reported by Huang and Chi (2011) respectively. This could have been caused by difference in maturity and weight of hosts used. Pupa survival (97.7%) at 30°C in pumpkin (*C. pepo*) is higher than 97.25% reported by Liu and Ye (2009) for *B. correcta* reared in the artificial diet. Species and host differences could explain the reason. Generally, survival of immature stages of *B. cucurbitae* increased with increase ambient temperature. This implies that temperature is an important factor in the biology of insect. According to Thierry and Serge (2000) temperatures play a key role in the insect breeding process. Vayssieres *et al*. (2008) pointed out that ambient temperature is known to be an important abiotic factor affecting immature development of insects.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Incidence of cucurbit fruit flies in cucumber

Cucurbit fruit fly species namely *B. cucurbitae*, *D. bivittatus* and *D. frontalis* infest both immature and harvestable cucumber fruits. Among the three cucurbit fruit fly species *B. cucurbitae* had high incidence in both immature and mature cucumber fruits followed by *D. bivittatus* and *D. frontalis*.

5.1.2 Infestation rate of cucurbit fruit flies in cucumber

For all selected cucurbit fruit fly species in cucumber fruit stages, *B. cucurbitae* had high infestation rates followed by *D. bivittatu*s and *D. frontalis*. Immature cucumber fruit was highly infested by cucurbit fruit flies than mature fruit stage.

5.1.3 Developmental time of *B. cucurbitae* immature stages

Developmental time of *B. cucurbitae* immature stages (egg, larval and pupal) increased with decrease in temperature from 30 to 20°C. Furthermore the pest had almost the same developmental duration among tested cucurbitaceous hosts.

5.1.4 Survival of *B. cucurbitae* immature stages

Survival of *B. cucurbitae* immature stages (egg, larval and pupal) increased with increase in temperature from 20°C to 30°C. Developmental survival rates of *B. cucurbitae* were nearly the same among the tested cucurbitaceous hosts.

5.2 Recommendations

The study provides data that are Pre- requisite for fruit fly species rearing. The necessary information from this study includes incidence and infestation rate of fruit fly species in cucumber fruit stages and the effect of temperature and cucurbitaceous hosts in the developmental time and survival of premature stages of *B. cucurbitae*.

5.2.1 Studies on incidence and infestation rate on other cucurbits

Further studies on incidence and infestation of cucurbit fruit fly species on other cucurbit fruit stages in different seasons and agro ecological zones should be conducted. The studies will add information on cucurbit fruit fly species forecasting and ecologically based management.

5.2.2 Studies on duration and survival on other cucurbit fruit flies

Studies on developmental duration and survival of *D. bivittatus* and *D. frontalis,* in commercial hosts (*C. sativus*, *C. lanatus* and *C. pepo*) in different temperature regimes and humidity need to be conducted. This information is useful for fruit flies rearing conditions in the laboratory that are necessary for biological studies and control methods such as releases of sterile flies for eradication programmes or releases of parasitoids for biocontrol.

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APPENDICES

Appendix 1: Temperature, relative humidity, and rainfall at Sokoine University of Agriculture

January –August 2012	Average Monthly Temperature (°C)		Total Monthly Rainfall (mm)	Average Rel. Humidity (%)
	Min	Max		
November	21.3	32.4	37	72
December	21.5	31.5	191.1	75
January	21.5	31.3	70.3	56
February	21.5	33.1	71.7	88
March	21.3	33.1	105.9	54
April	20.5	31.6	124.9	62
May	19.3	29.9	134.6	62
June	17	28.7	22.9	54
July	15.8	28	1.9	47
August	19.9	29.4	9.7	46
Total	**199.6**	**309**	**770**	**616**
Mean	**19.96**	**30.9**		**61.6**

Source: TMA Morogoro (2012)

Appendix 2: ANOVA table for egg incubation period of *B. cucurbitae* in three cucurbit fruit species at three temperature regimes

Source of variation	df	ss	ms	F–value	F–probability
Host	2	0.04743	0.02371	1.02	0.381
Temperature	2	4.69210	2.34605	100.70	0.001
Host x Temperature	4	0.10157	0.02539	1.09	0.391
Residual	18	0.41933	0.02330		
Total	26	5.26043			

Appendix 3: ANOVA table for larva developmental time of *B. cucurbitae* in three cucurbit fruit species at three temperature regimes

Source of variation	df	ss	ms	F–value	F–probability
Host	2	0.6585	0.3293	1.22	0.319
Temperature	2	34.2985	17.1493	63.43	< 0.001
Host x Temperature	4	1.5259	0.3815	1.41	0.270
Residual	18	4.8667	0.2704		
Total	26	41.3496			

Appendix 4: ANOVA table for pupa developmental time of *B. cucurbitae* in three cucurbit fruit species at three temperature regimes

Source of variation	df	ss	ms	F–value	F–probability
Host	2	0.9830	0.4915	1.04	0.372
Temperature	2	210.175	105.0893	223.42	< 0.001
Host x Temperature	4	4.7304	1.1826	2.51	0.078
Residual	18	8.4667	0.4704		
Total	26	224.355			

Appendix 5: ANOVA table for total developmental time from egg to adult of *B. cucurbitae* in three cucurbit fruit species at three temperature regimes

Source of variation	df	ss	ms	F–value	F–probability
Host	2	3.461	1.730	0.96	0.403
Temperature	2	489.010	244.505	135.25	< 0.001

Host x Temperature	4	11.859	2.965	1.64	0.208
Residual	18	32.540	1.808		
Total	26	536.870			

Appendix 6: ANOVA table for egg survival rate (%) of *B. cucurbitae* in three cucurbit fruit species at three temperature regimes

Source of variation	df	ss	ms	F–value	F–probability
Host	2	0.0001881	0.0000940	0.62	0.548
Temperature	2	0.0503669	0.0251834	167.11	< 0.001
Host x Temperature	4	0.0001885	0.0000471	0.31	0.865
Residual	18	0.0024112	0.0001507		
Total	26	0.0533137			

Appendix 7: ANOVA table for larva survival rate (%) of *B. cucurbitae* in three cucurbit fruit species at three temperature regimes

Source of variation	df	ss	ms	F–value	F–probability
Host	2	0.0000178	0.0000089	0.01	0.989
Temperature	2	0.0428584	0.0214292	25.56	< 0.001
Host x Temperature	4	0.0002342	0.0000586	0.07	0.990
Residual	18	0.0134159	0.0008385		
Total	26	0.0566583			

Appendix 8: ANOVA Table for pupa survival rate (%) of *B. cucurbitae* in three cucurbit fruit species at three temperature regimes

Source of variation	df	ss	ms	F–value	F–probability
Host	2	0.0000468	0.0000234	0.20	0.821
Temperature	2	0.0492920	0.0246460	210.14	< 0.001
Host x Temperature	4	0.0002009	0.0000502	0.43	0.786
Residual	18	0.0002009	0.0001173		
Total	26	0.0515227			

Appendix 9: ANOVA table for incidences of three fruit fly species in two cucumber fruit stages

Source of variation	df	ss	ms	F–value	F–probability
Rep	2	0.0050545	0.0025273	5.80	
Stage	1	0.0073298	0.0073298	16.82	0.055
Residual	2	0.0008717	0.0004359	0.46	
Fly	2	0.0552104	0.0276052	28.92	<.001
Stage x Fly	2	0.0061376	0.0030688	3.21	0.094
Residual	8	0.0076365	0.0009546		
Total	17	0.0822406			

Appendix 10: ANOVA table for infestation rates of three fruit fly species in two cucumber fruit stages

Source of variation	df	ss	ms	F–value	F–probability
Rep	2	1218.92	609.46	33.78	
Stage	1	1988.70	1988.70	110.24	0.009
Residual	2	36.08	18.04	0.19	
Fly	2	26385.44	13192.72	135.73	<.001
Stage x Fly	2	4028.77	2014.38	20.72	0.009
Residual	8	777.60	97.20		
Total	17	34435.52			