ASSESSMENT OF SEASONAL EFFECT ON MAJOR INSECT PESTS OF TOMATO IN JEGA, KEBBI, NIGERIA WITH EMPHASIS ON WHITEFLY (*Bemisia tabaci* GENNADIUS)

By

MUHAMMAD KWAIFA NASIRU

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2024

FP 2024 22

DEDICATION

This work is dedicated to my Late beloved Mother Malama **Aisha** Abubakar Magina of blessed memory, my **Father**; **Alhaji Muhammad Kwaifa** (The King of Kwaifa), my beloved **Wife; Rabi'a Sai'id**, and my 7 beloved **Children; Habib, Muaz, Sadiq, Aishah-Ummi, Faruq, Amina and Zainab Nasiru Kwaifa** for their perseverance and endurance during my study period.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Associate Professor Ts. Nur Azura binti Adam, PhD
Faculty : Agriculture

Despite these serious losses (up to 50% annually) caused by insect pests on tomato, there is no adequate information on the types of insect pests attacking and causing damages to tomato in Jega, Kebbi, Nigeria. The need to investigate and assessed the insect pests affecting tomato in relation to the major climatic factors lead to this study with the following objectives: (1) to monitor the major field insect pests on tomato crops in the dry and rainy seasons; (2) to investigate the seasonal abundance of *Bemisia tabaci* abundance on tomato as affected by environmental temperature, humidity and rainfall; (3) to determine the seasonal effect of different life stages of *B. tabaci* on tomato yield in net-covered plots in relation to climatic factors (4) to determine the seasonal infestation of different life stages of *B. tabaci* on tomato yield in the field in relation to climatic factors. Studies were conducted in the dry and rainy seasons of 2017 and 2018, at the University Teaching and Research Farm, Kebbi State University of Science and Technology, Jega (Latitude 12^{o} 11ʹ N; Longitude 4^{0} 16ʹ E). Sampling of insects were conducted through visual count in objective 1, 3 and 4 while sticky trap was done in objective 2. All experiments were laid out in Randomized Complete Block Design (RCBD. Data on the abundance were subjected to Analysis of Variance while data for the abiotic study were subjected to Pearson's Correlation analysis performed in SAS version 9.4. Result revealed six major insect pests recorded on tomato in the study location namely; Leafhopper: *Empoasca fabae,* Aphid: *Macrosiphum euphorbiae*, Whitefly: *Bemisia. tabaci,* Fruit worm: *Helicoverpa armigera*, Flea Beetle: *Epitrix hirtipennis* and Mealybug: *Phenacoccus solenopsi*. Leafhopper: *E. fabae* was significantly ($P<0.05$) the highest in abundance than all the other insect monitored in both seasons and and in both years, followed by Aphid *M. euphorbiae* and whitefly *B. tabaci.* Flea Beetle *E. hirtipennis, fruit worm H. armigera* and mealubug *P. solenopsi* were significantly ($P<0.05$) lower than *E. fabae*, *M. euphorbiae* and *B. tabaci* in both seasons in 2017 and 2018. Temperature and relative humidity significantly correlated positively ($P<0.05$) with tomato insect pest abundance with the exception of rainfall that correlated significantly ($P<0.05$) negative. *Bemisia tabaci* abundance was found to be positively correlated with temperature and relative humidity however it was negatively correlated with rainfall. The net house experiment showed that *Bemisia tabaci* infestation significantly ($P<0.05$) reduced the growth and performance of tomato by decreasing the number of flowers and fruit produced. The infestation significantly increased ($P<0.05$) tomato plant mortality and number of irregular fruit ripening on tomato. Similar result were also obtained on the experiment conducted in open field where the abundance of different life stages reduced the growth, yieald quality and quantity of tomato. The result of this study will be the first useful information obtained that will assist in formulating an effective pest management and control system on the insect pests affecting tomato in the studied area.

Keywords: whitefly, Bemisia tabaci, seasonal effect

SDG: GOAL 2: Zero Hunger, GOAL 13: Climate Action

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN KESAN BERMUSIM TERHADAP SERANGGA PEROSAK UTAMA TOMATO DI JEGA, KEBBI, NIGERIA DENGAN PENEKANAN PADA LALAT PUTIH (*Bemisia tabaci* GENNADIUS)

Oleh

MUHAMMAD KWAIFA NASIRU

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Walaupun kerugian serius (sehingga 50% setiap tahun) disebabkan oleh serangga perosak pada tomato, tiada maklumat yang mencukupi tentang jenis serangga perosak yang menyerang dan menyebabkan kerosakan pada tomato di Jega, Kebbi, Nigeria. Keperluan untuk mengkaji dan menilai serangga perosak yang menjejaskan tanaman tomato berhubung dengan faktor iklim membawa kepada objektif kajian ini seperti berikut: (1) memantau serangga perosak utama pada tanaman tomato pada musim kering dan hujan; (2) menyiasat kelimpahan bermusim *Bemisia tabaci* pada tomato yang dipengaruhi oleh suhu persekitaran, kelembapan dan hujan; (3) menentukan kesan bermusim peringkat kehidupan yang berbeza *B. tabaci* terhadap hasil tomato dalam plot tertutup berkait dengan faktor iklim (4) menentukan serangan bermusim peringkat kehidupan *B. tabaci* yang berbeza ke atas hasil tomato berkait dengan faktor iklim. Kajian telah dijalankan pada musim kering dan hujan pada tahun 2017 dan 2018, di Ladang Pengajaran dan Penyelidikan Universiti, Kebbi State University of Science and Technology, Jega (Latitud 12° 11’ U; Longitud 40 ° 16’ T). Persampelan serangga dijalankan melalui kiraan visual dalam objektif 1, 3 dan 4, manakala penggunaan perangkap lekit kuning bagi objektif 2. Semua eksperimen telah dijalankan dalam Reka Bentuk Blok Rawak Lengkap. Data kelimpahan dianalisa menggunakan Analisis Varians manakala data untuk kajian abiotik dianalisa menggunakan Analisis Korelasi Pearson dan semuanya dilaksanakan dalam SAS Versi 9.4. Hasil kajian menunjukkan enam serangga perosak utama yang direkodkan pada tomato di lokasi kajian iaitu lelompat: *Empoasca fabae,* afid: *Macrosiphum euphorbiae*, lalat putih: *Bemisia. tabaci,* ulat buah: *Helicoverpa armigera*, kumbang lenting: *Epitrix hirtipennis* and koya: *Phenacoccus solenopsi*. Kelimpahan lelompat *E. fabae* adalah yang tertinggi secara signifikan ($P<0.05$) berbanding kelimpahan serangga lain pada kedua-dua musim dalam tahun 2017 dan 2018, diikuti oleh kelimpahan afid *M. euphorbiae* dan lalat putih *B. tabaci*. Kumbang lenting *E. hirtipennis, ulat buah H. armigera* dan koya *P. solenopsi* adalah jauh lebih rendah ($P<0.05$) berbanding *E. fabae, M. euphorbiae* dan *B. tabaci* pada kedua-dua musim pada kedua-dua tahun 2017 dan 2018. Suhu dan kelembapan relatif adalah signifikan berkorelasi secara secara positif ($P<0.05$) dengan kelimpahan serangga perosak tomato kecuali hujan yang berkorelasi secara negatif ($P<0.05$). Kelimpahan *Bemisia tabaci* didapati berkorelasi secara positif dengan suhu dan kelembapan relatif namun ia berkorelasi negatif dengan hujan. Eksperimen di dalam rumah jaring menunjukkan bahawa serangan *Bemisia tabaci* secara signifikan ($P<0.05$) mengurangkan pertumbuhan dan prestasi tomato dengan mengurangkan bilangan bunga dan buah yang dihasilkan. Serangan meningkat dengan ketara ($P<0.05$) ke atas mortaliti pokok tomato dan bilangan buah tomato masak yang tidak sekata. Keputusan yang sama juga diperoleh pada eksperimen yang dijalankan di ladang terbuka di mana kelimpahan peringkat hidup yang berbeza mengurangkan pertumbuhan, kualiti hasil

dan kuantiti buah tomato. Hasil kajian ini akan menjadi maklumat berguna pertama yang diperoleh yang akan membantu dalam merumuskan sistem pengurusan dan kawalan perosak yang berkesan terhadap serangga perosak yang menjejaskan tomato di kawasan kajian.

Kata Kunci: lalat putih, Bemisia tabaci, kesan bermusim

SDG: MATLAMAT 2: Kelaparan Sifar, MATLAMAT 13: Tindakan Iklim

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Date: 24 February 2025

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

L.	Linnaeus
FAOSTAT	Food and Agriculture Organisation Corporate Statisitical Database.
t ha^{-1}	Tonne per Hactare.
EPPO	European and Mediterranian Plant Protection Organisation.
CABI	Centre for Agricultural and Bioscience International.
TYLCV	Tomato Yelloew Leaf Curl Virus.
ToMoV	Tomato Mottled Virus.
SPP	Species.
CMBV	Cassava Mosaic Begomovirus.
CBSV	Cassava Brown Streak Disease.
CMD	Cassava Mosaic Disease.
IITA	International Institute of Tropical Agriculture.
NPC	National Population Commission.
NPC	National Population Commission.
KASCOM	Kebbi Agricultural Supply Company.
Kg	Kilogramme.
SSP	Super Super Phosphate.
MP	Muriate of Potash.
ANOVA	Analysis of Variance.
PROC	Procedure.
GLM	General Linear Model.
SAS	Statistical Analysis System.
Inc.	Incorporated.
RCBD	Randomised Complete Block Design.
LSD	Least Significant Difference.

ºC	Degree Celcius.
M	Metre.
CM	Centimetre.
YST	Yello Stiky Traps.
P	Probability
R	Multiple Correlation Coefficient
r	Simple Correlation Coefficient

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Tomato (*Solanum* l*ycopersicum* L.) is among the most important vegetable crops valued and produced all over the world today, with an average yield of about 100 million tons from 3.7 million hectares of cultivated land, tomato ranks second after potato according to the area cultivated (FAOSTAT, 2023). In Africa the crop is commonly cultivated around Guinea Savannah mostly in the wet season and Sudan Savannah in the dry season through irrigation scheme (Emenike and Emuh, 2015 and Willa Dunn *et al.* (2020). In Africa the average yield of 8-25 t ha^{-1} was recorded, with the highest yield from South Africa and the least from Benin and Nigeria (Umeh *et al.*, 2002; Maina and Maina, 2012).

The usefulness of tomato as a crop contributes greatly to its popularity as a staple food which can be processed and tinned easily as a whole or as a paste; Juice, sauce or powder, eaten raw, alone or in a mixture with other foods. Main tomato producing states in Nigeria are Kano, Kebbi Jigawa, Kaduna, Gombe, Sokoto, Bauchi, Zamfara, Katsina, Borno and Benue all in the northern parts (Ugonna *et al.,* 2015). Tomato fruits provide Vitamins A, C, and B complex that function in the prevention eye and skin infections (Enujeke and Emuh, 2015; Aliyu *et al*., 2016).

1.2 Problem Statement

Tomato is produced for several years by farmers in Nigeria but with yields usually that are lower between 5-20 tones/ha, because of using lower yielding crop varieties, low soil fertility, weed, diseases and insect infestation (Akintoye, 2003 and Olaniyi *et al*., 2010). Nigeria is the highest country in terms of population in Africa also the 7th most populous the world over and is expected to reach over 400 million by the year 2050, meeting the domestic demand for foods therefore is the most challenging. Tomato which is a basic part a staple foods of the majority of the population in Nigeria, thus making it availability very crucial (Edon, 2016). Among the highly damaging and most notorious problems affecting tomato in Nigeria are the different insect pests that annually destroyed the crop on the farms. Notably, whitefly is *Bemisia tabaci*, was found to be a major insect pest o tomato the world over and Nigeria may not be an exception, which can feed from over 500 different host plants such as Tomato; *Solanum lycopersicum,* Peppers; *Capsicum spp.*, Cassava; *Manihot esculenta*, Cotton; *Gossypium spp.*, Sweet potato; *Ipomoea batatas*, Tobacco; *Nicotiana tabacum*, Okra; *Abelmoschus esculentus* and Egg plant; *Solanum melongena* among others, causing serious damages of up to 100% in some of these crops all over the world, with this insect having approximately 41 morphologically indistinguishable biotypes (De Barro *et al.*, 2005). The pest attack on many different host crop often decreasing harvests by over 50% because the synergistic effects of their feeding from phloem and their vectoring of viruses that affect plants (Tatiyana *et al*., 2014). During feeding the pest transmits viral disease such as Tomato Yellow Leaf Curl Disease (TYLCD) andTomato Mottle Disease Virus (ToMoD) on major crop plants; including tomato, cassava, cotton, okra, tobacco and sweet potato in Nigeria leading to serious damages on the crop and subsequently, killing the plants. Direct feeding damage is not usually of importance, but viruses transmitted during feeding can cause serious yield losses (Moshe *et al*., 2014).

1.3 Justification of the Study

Tomato is among the most vital vegetable crops produced in Nigeria and it is considered as one of the very useful vegetable next to pepper and onions constituting 18% of the diet (Olaniyi *et al*., 2010; Dunn *et al*., 2020). Domestic demand for tomatoes in Nigeria used as a staple food exceeds supply with over 2.3 million metric tons of the crop annually (Banjo, 2013: Edon, 2016), with an annual worth above 90 Billion USD (FAOSTAT, 2019). Considering the importance of tomato as a daily dietary requirement and its contributions in the national as well as global economic growth and development and the detrimental effects of insect pests on tomato a study of this nature is therefore needed to understand the nature and atime of abundance of th major insect pests destroying tomato in order to improve upon the quantity and quality of the crop produced in the study location.

There are no assessments on seasonal abundance and whitefly incidence on any cultivated crop in the study area located in the north-western parts of Nigeria, however, Banjo (2013) observed that infestation of plants by whiteflies in southern Nigeria is high and needs to be controlled. This knowledge gap in the study area makes it impossible to plan and implement any strategies aimed at controlling insect pests affecting tomato production in southern Nigeria. Seasonal monetary losses of between 1,490 and 17,555 Naira ptoer hectare have been recorded which are attributed to insect pests attack such as fruit worms or borers, armyworms, leaf miners and leaf feeders (Umeh *et al.*, 2002). Roughly 1, 000 square kilometres hectare of land is approximated to produce 5 to 20 tonnes of tomato fruits, whereas in the United States, Italy, and China, tomato could produce about 50 to 80 tonnes per hectare (Olaniyi *et al*., 2010; Thriveni, 2019).

Studies on the abundance of *B. tabaci* is not aimed at knowing the exact number of the insects, but rather how the abundance affects the crop plants in the study sites. The knowledge gap created by the scarcity of data on the time of abundance, number of species, and distribution and host plants of whiteflies in North-western Nigeria is the major constraint to the management of the pests on tomato. Past surveys of whiteflies in Nigeria were often limited to certain agricultural plants like cassava, tobacco and citrus (Oyelade and Ayansola, 2015), this work covered the study on majorinsect pests giving more emphasisi on whitefly infestation on tomato crop in relation to the climatic factors in the study area.

For developing a weather based pest forewarning system, information regarding population dynamics in relation to prevalent meteorological parameters (temperature, relative humidity, sun shine hours) is needed. Moreover, the same meteorological parameters also influence the growth and development of crop. Therefore, a thorough understanding of interaction between the crop growth stage and meteorological parameters/pest dynamics is a prerequisite for weather based pest forecasting model. Hence, the present studies will be focused on location specific seasonal occurrence of insect pests of tomato with emphasis on whiteflies in relation to the three different climate factors; temperature, rainfall and relative humidity.

Therefore, the specific objectives of this study are:

1. to monitor the major field insect pests attacking tomato crop in dry and rainy seasons.
2. to investigate the seasonal abundance of *Bemisia tabaci* on tomato as affected by environmental temperature, humidity and rainfall.

3. to determine the seasonal effect of different life stages of B*emisia tabaci* on tomato yield in net covered plot in relation to climatic factors.

4. to determine the seasonal infestation of different life stages of B*emisia tabaci* on tomato yield in the field in relation to climatic factors.

CHAPTER 2

LITERATURE REVIEW

2.1 Tomato

2.1.1 Tomato Production

Tomato (*Solanum lycopersicum* Miller) is a member of the Solanaceae family and one of the most widely cultivated vegetable crops in the world with a total global production of about 3.7 million metric tonnes per annum in the last ten years it is the world's largest vegetable crop after potato and sweet potato but it tops the list of canned vegetables (FAOSTAT, 2023). The crop is the most important fruit vegetable produced globally next to potato (Nurul Huda *et al*., 2022). Tomato acreage increased by almost threefold in the last 50 years to around five million hactares in 2015 as stated in the Database of the European Union countries that are among the top tomato producers in the world, with about 85% of tomatoes produced outdoors in the countries around the Mediterranean areas (Eurostat, 2019). At present, the world tomato production has reached about 100 million tonnes of fresh fruits produced on 3.7 million hectares from 144 countries, with China (1,255,100 metric tonnes) and the Netherlands (4,166,667 metric tonnes) being the major producers around the world (FAOSTAT, 2010). The United Nations Food Security Programme estimated the national yield average to be 25 tonnes/ha per country, compared with that of U.S.A producing as high as 110.7 tonnes/ha (FAOSTAT, 2022; Marchant *et al*., 2020).Africa is reported to export almost $800 million from tomatoes in 2015 which is about 10% of the world's total production, the region produced about $6.9 billion worth of tomato back in 2013, as estimated by the Food and Agriculture Organisation estimates (Ugunna, 2015). The average yield of tomato in some African countries is about 8-25 t ha^{1}, with the highest yield from South Africa and the least from Benin and Nigeria (FAOSTAT, 2022).

In Nigeria, about 200,000 ha of fertile land is fadama land (riverine), mainly situated along the flood plains of the Rima and Niger valleys, the rest is upland, dominated by main smallholders farmers, that supports large-scale production of other crops such as millet, guinea corn, rice, wheat, beans, groundnut, cotton, tobacco, sugar cane, sweet potatoes, and vegetables like onion, pepper, and tomatoes (Olaniyi *et al*., 2010). The crop is produced by over 200,000 farmers in Nigeria, who produced over 1.5 million metric tonnes of tomatoes annually (Edon, 2016). About 70 million tons of tomato is produced commercially the world over in over 2 million hectares of land, but less than 20% of this tomato is produced in tropical regions (Muhammad *et al*., 2014). In semi-arid regions like the Northen parts of Nigeria (Sokoto, Kebbi and Borno States), low humidity and high summer temperatures caused by high levels of radiation, limit the production of tomato suitable only during the cooler part of the year, and this leads to the seasonality of the crop production (Abdelmageed and Gruda, 2007). It grows in a wide temperature range of 15°C–35°C with optimal temperatures of between 23°C–27°C.

The yield per hectare for producing tomatoes in Nigeria is about 5 to 6 metric tonnes per hectare whereas in the developed countries tomato producing countries produce about 50 to 60 metric tonnes per hectare (FAOSTAT, 2010: Osagie, 2016). In 2010 the production of tomatoes in Nigeria has reached about 1.8 million metric tonnes, which accounts for about 68.4% of the production in Africa (Edon, 2016). Being the crop a very important fruit as it is a main source of a vital component in varieties of foods and a very cheap source of vitamins, it contains large quantity of water, calcium, and Niacin that are of great significance in the metabolic activities of man (Wade *et al.,* 2020; Nurul Huda *et al.,* 2022). The crop is also a very good vitamin C source, minerals, manganese as well as vitamin E, providing phytonutrients and carotenoids like lycopene, zeaxanthin and beta-carotene and reduce the danger of heart related diseases and many health benefits from tomatoes fruits (Kabura *et al*., 2009).

2.1.2 Origin and Distribution of Tomato

Tomato (*Solanum lycopersicum* Miller) originated from the tropics of Central and South America, ranked as the world's most widely grown vegetable crop (Muhammad *et al*., 2014). The crop was believed to have its origin in Peru-Ecuador areas where it spreads as a weed throughout many parts of America thereafter domesticated in Mexico (Jaliya, *et al.,* 2007). Soon after the discovery and domestication, it became very popular and widely distributed in humid and sub-humid tropical environments and has since been adapted to different of climatic variation.

2.2 Insect Pests of Tomato

Tomato yield could be increased significantly through better agronomic practices and the lessening of pests and diseases on the crop because soon as tomato plants emerged out, they are susceptible to attack by diverse insect pests, which comprise *B. tabaci*, aphid, *Aphis craccivora*, beetles such as *E. hirtipennis*, fruit worms such as *H. armigera*, that destroy young tomatoes seedlings on nursery beds and in the fields (Webb *et al*., 2001; Edon, 2016). The crop is further subjected to different forms of attacks by a great number of insect pests from the time the plants first appeared in the seedbed till harvest. The crop is affected by many biotic, physiochemical and mesobiotic factors among which insect pests are the main problems affecting tomato and occur regularly at different stages of crop growth, with about 100 insect pests species (such as different species of Leafhoppers, Aphids, Whiteflies and Tomato worms) reported to attack the tomato farms (Devinder *et al*., 2020). According to Awan, (2012), the world domestic consumption and demand for tomato are growing due to the increase in human population.

Furthermore, sting bugs and fruit worms cause extreme destruction to the tomato fruits in the field and aphids, stink bugs, and fruit worms cause insignificant damage to the foliage (Brezeanu *et al*., 2014). There are many insect pests of tomato prevalent in tomato producing areas of about 1,556 species are known to comprise the Aleyrodidae family alone, in the subgroup of Hemiptera, the Family Aleyrodidae is further subdivided into three subfamilies: Aleurodicinae, Aleyrodoidea and Udamoselinae (Tatiana *et al*., 2014). Tomato insect pests such as whiteflies and aphids cause severe damage to crop by transmitting viral disease (Kumar *et al*., 2020; Wade *et al.,* 2020). The tomato fruit borer, *Helicoverpera armigera* (Hubner) is a key pest and cause up to 40-50 per cent damage to the tomato crop (Ceceilia *et al*., 2013). In Nigeria, the yield per unit space of land cultivated is by far lower than what previously obtainable and when compared to other nations such as the United States, Italy and China (Osagie, 2016). The yield of tomato in Nigeria is generally low at present, the average in the western areas of the country being only about 5 tonnes per hectare while in the Northern parts of Nigeria is about 10 tonnes per hectare (Olaniyi *et al*., 2010).

However, serious damage may result also from their feeding activity on the fruit or by serving as vectors of diseases. At least 27 arthropod pests have the potency of extremely reducing both yields and the market value of tomato fruit (Bloem & Mizell, 2004). Reports from Umeh *et al*. (2002) and Wade *et al,* 2020, revealed that the main insects attacking tomato in the in some tomato producing areas comprised of *Aphid gossypii*, *Zonocerus variegatus* L., *Helicoverpa armigera*, *Bemisia tabacci* and other species of aphids, mostly *Aphis gossypii* Glover.

2.2.1 Nature of Insect Pest Damage on Tomato

Both immature and adult insects such as aphids, leafhoppers and whiteflies feed on the phloem of the leaves and stems by injecting a sucking mouthpart into the leaf, thus transferring the virus to the plant through the saliva from the mouth into the plant, thereby, disrupting plant growth and eventually decreasing yield, plant seedlings are adversely affected (Adjata *et al.*, 2012). Feeding by the juvenile sweet potato whitefly causes plant distortion, discolouration, or silvering of leaves, and may lead to serious damages (due the spread of viral diseases) in some vegetable crops by prudently manoeuvring its stylet through the epicuticular layer, epidermis, and spongy tissue to reach the phloem (Freeman *et al*. 2001; Firdaus *et al.*, 2012).

According to Ceceilia *et al*. (2013) Tomato Fruit worm; *Heliothis armigera* Hubner (Lepidoptera: Noctuidae) is also among the most common insects that attacks and destroy both flowers and pods of tomato, it's a polyphagous and sporadic Moth which is an insect pest of cowpea and tomato, with the larvae feeding on leaves, flower buds, flowers, green pods and fruits, while the adults of *H. armigera* are found to be grey to brown in colour while females lay their eggs singly, mostly destroying younger leaves, flowers and stems of tomato plants. The Eggs of *H. armigera* are hatched in about 3-8 days, undergoing six larval instars, with a larval period lasting from 14-35 days, subject to weather situations (Singh, 1990). The larvae have longitudinal marks on each side of their body often dark brown or green, pupation takes place inside the soil, about 40 mm deep in the tropics and lasts for 9 to 16 days (Nombela *et al*., 2009). Mealy bug is another insect pest of tomato that damages the plants by sucking sap from roots, tender leaves, petioles and fruit emitting honeydew on which sooty mould develops, that rigorously infected leaves making them to turn yellow and steadily dry out with time (Canaria *et al*., 2017). Serious attack from Mealybugs can result in the loss plant leaves and flowers, reduced fruit setting and leaf falling in young fruit (Ofori *et al*., 2014). The foliage and fruit may become enclosed with sticky honeydew that aids as a medium in the formation of the sooty moulds. Honeydew, sooty mould and waxy deposits could cover leaves thereby reducing photosynthetic proficiency and could lead to leaf shading and poor growth and development (Canaria *et al*., 2017). This honeydew and sooty mould secreted by these Mealy bugs on fruits (as in whitefly) reduced its market value, this secretions are also found on tomato leaves and stems which invites ants, these ants gather the honey on the plants thereby shielding the Mealy bugs from attack from its natural enemies. Mealy bugs inject toxic substances as it is feeding which leading plant deformation (such as the cassava mealy bug). Certain species such as the pineapple mealy bug can also transmit viruses.

2.3 Taxonomy of *Bemisia tabaci*

The genus *Bemisia* comprises of 37 species and is believed to have originated from Asia (Aline *et al*., 2008). *Bemisia tabaci*, being probably of Indian origin was described under several names before its morphological variability was recognized (Fishpool *et al*., 2009). About 1,556 species belonging to the Aleyrodidae family, a subgroup of Hemiptera, the Aleyrodidae is further subdivided into three sub-families:

Aleurodicinae, Aleyrodidae, and Udamoselinae (Tatiana *et al*., 2014). Their genetic groups are composed of at least 34 morphologically indistinguishable species (De Barro *et al*., 2011; Boykin and De Barro, 2014).

2.4 Biology of *B. tabaci*

Whitefly, *B. tabac* larvae is asbout 1 mm long, the females are bigger than males in size and both pairs of wings usually covered with a powdery, waxy secretion, white to slightly yellowish and distinguishing the different species of whitefly is difficult, morphology of adult eye is usually depicting variations as a result of an ommatidial arrangement between species (Chris *et al*., 2017). When at resting position, *B. tabaci* has wings are collapsed onto the body more than in *Trialeurodes vaporariorum* that is bigger and three-sided in appearance than *B. tabaci* (EPPO/CABI, 2018). Adults are minute usually about 1.5 mm long, yellowish insects possessing white wings. Sweet potato whiteflies hold their wings slightly vertically slanted forming a roof-like appearance, the wings do not meet over the back but have a small space separating them (Bellows *et al*., 1995). Adult *T. vaporariorum* is very similar in appearance to the *B. tabaci* but grasp their wings flatter over the back and there is no space between the wings where they meet in the centre of the back, the Banded winged whiteflies, *Trialeurodes abutilonia,* have greyish or brownish bands across their wings (Lima *et al*., 2000).

2.5 Nature of Damages Caused by *B. tabaci*

Both immature and adult whiteflies feed on the phloem of the leaves by injecting a sucking mouthpart into the leaf, thus transferring the virus to the plant through the saliva from the mouth into the plant, thereby, disrupting plant growth and eventually decreasing yield, plant seedlings are adversely affected (Adjata *et al.*, 2012). Feeding by the juvenile sweet potato whitefly causes plant distortion, discolouration, or silvering of leaves, and may lead to serious damages in some vegetable crops by prudently manoeuvring its stylet through the epicuticular layer, epidermis, and spongy tissue to reach the phloem (Freeman *et al*. 2001). The stylet is wrapped with a gel-like substance that reduces plant defence responses. Whitefly infestation can cause substantial loss of plant vigour and yield, leading to early wilting, leaf chlorosis and defoliation (Firdaus *et al.*, 2012). *B. tabaci* produce honeydew which contains sugars and amino acids, which is a good substrate for sooty mould growth (McCollum *et al.*, 2011) that can cover the plant's surface including leaves, stems, and fruits. Among the diseases spread by *B. tabaci* is Tomato Yellow Leaf Curl Disease (TYLCD) characterized by severe chlorosis and necrosis on infected leaves, giving them a yellowish and mottled appearance (Winter *et al.*, 2010). Heavy sooty mould growth reduces photosynthesis and results in physiological disorders such as irregular fruit ripening and economically it is one of the most important pests of tomato and pepper (Basu, 2019: Morales and Anderson, 2007; Time *et al.*, 2020). This insect causes yield losses of nearly 50% reported due the spread of Cassava Mosaic Disease (CMD) leadig to severe food shortages and localised famine in the African in some countries (Ario *et'al.,* 2005)

2.5.1 Plant Disease Pathogens Vectored by Whitefly

2.5.1.1 Tomato Yellow Leaf Curl Disease Virus (TYLCV)

The virus known as Tomato Yellow Leaf Curl Virus (TYLCV) was initially considered as a virus transmitted by whitefly by spreading the virus in tomato (*S.*

lycopersicum) crops in Israel (Cohen and Nitany, 2004) and later confirmed as a Geminivirus (small stranded viruses infecting crop) asstated by Sanjeeb *et al*. (2019). TYLCV species have been recognized as and confirmed to be vectored by whitefly using molecular data and was allocated in the Genus called Begomovirus, Family Geminiviridae (Boykin and De Barro, 2014). TYLCV had been considered as a highly destructive virus causing disease to the cultivated tomato (*S. esculentum*) in humid tropics and warm temperate areas globally, leading to 100% destruction (Moriones *et al.*, 2000).

TYLCV has been documented in tomato crops infested by whitefly In Europe particularly France, Italy, Portugal and Spain, in addition to this it is prevalent in many eastern Mediterranean countries as reported by Sameena *et al.* (2019) and certain regions of Saharan Africa, Asia, Australia including Caribbean regions. In Europe, two species of TYLCV, namelyTomato Yellow Leaf Curl-Sardina (TYLCV-Sar) and Tomato Yellow Leaf Curl-Israel (TYLCV-Is), were identified as reported by Moriones *et al*, (2000), described using the taxonomic nomenclature described by Fargette *et a*l. (2000). Symptoms of these diseases differ based on the stages of growth of tomato, period the infection begins, ecological situations and the variety of tomato plant leading to severe stunting, a marked decrease in leaf size area, upper cupping, yellowish/chlorosis the leaf margins, twisting, flower fall and substantial reduction in yield (Marchant *et al*., 2020). *Bemesia tabaci* as the disease vector transmits TYLCV (spp.) in a persistent, circular manner and is the main vector of TYLCV *spp* (Cohen and Nitany, (2007). No established evidence of the TYLC virus as seed born in tomato as well no reports of mechanical transmission occurring naturally Moriones *et al.*, 2000).

2.5.1.2 Tomato Mottle Disease Virus (ToMoV)

The whitefly-transmits geminivirus called Tomato mottle virus (ToMoV) was initially reported in 1989 and documented by Book *et al*. (2022) and Abouzid and Hiebert (1992). Tomato crop in the southern and central regions of Florida (USA) was found infected with ToMoV and subsequently, the virus was detected in all tomato producing areas of Florida, a serious outbreak occurred in the 1990 to 1991 autumn and spring tomato crops estimated to have triggered a decrease in the value of the crop amounting to $125 million in south-western Florida only (Marchant *et al*., 2020). The ToMoV epidemics in temperate places such as Florida was established to be associated to a sporadic epidemics of the sweet potato whitefly (*Bemisia tabaci* (Gennadius) B. as reported by Bloem and Mizell (2004). ToMoV was consequently recorded on tomato in South Carolina, Tennessee, and Virginia (Polston *et al*., 2005). The virus was observed to spread mechanically and is highly infectious causing damages such as mottled leaves, leaf curling, stunted growth, leaf fall, spots on fruits, deformed fruits and fruit drop on tomato.

2.6 Host Plants of *B. tabaci*

Bemisia tabaci have extensive host range, involving more than 500 plant species transferable to more than 60 plant families (Morales and Anderson, 2007). *Bemisia tabaci* is regarded to be among highly destructive pests in agriculture, potential to cause serious damages in crops everywhere the world over, in both tropical and subtropical areas (Kajita and Alam, 1996). The insect is popularly recognized as a pest of field crops in humid and sub-humid countries on cultivated crops such as` tomatoes *L. esculentum*, *Manihot esculenta*, *Gossypium spp.*, *Ipomoea batatas*, *Lactuca sativa*, and *Nicotiana tabacum* (Pakkianathan and Murad, 2014), other hots plants include *Abelmoschus esculentus, Cucubita pepo, Euphorbia pulcherrima, Occimum basilicum, Phaseolus vulgaris and Brassica rapa* among others (De Barro *et'al*., 2011; EPPO/CABI, 2018). With the evolving of the very polyphagous biotype B. of whitefly, *B. tabaci* is at present considered as one of the most serious pest crops in the glasshouse in many regions of the world, particularly *Capsicum* spp., *Cucurbita pepo*, *Cucumis sativus*, *Hibiscus spp.*, *Gerbera spp.*, *Gloxinia spp., Lactuca sativa* and *Euphorbia pulcherrima* (De Barro *et al*., 2011). The pest *B. tabaci* travels without restrictions on different host types to alternative hosts and was projected to about 600 host types in *Asteraceae, Brassicaceae, Convolvulaceae, Cucurbitaceae, Euphorbiaceae, Fabaceae, Malvaceae, Solanaceae* (Pedigo, 2004). The insect have the ability of causing these damages through feeding by sucking the leaf sap, leading to the growth of sooty mould by its honeydew, spreading more than 111 species of plant-pathogenic viruses, and inducing plant physiological problems instigating global losses of more than $300 million yearly (Amy, 2018; Yaobin *et al.*, 2012).

2.7 Lifecycle of *B. tabaci*

From hatching, initial instar (crawler) appears which is flat, oval and scale-like, it is the lone larval stage of this insect that is mobile. This moves to a comfortable feeding site at the lower parts of the lower leaf where its legs are lost in the subsequent moult and the larva changes to become sessile (Li *et al*. (2022). Consequently, these larvae do not move again during the remaining nymphal stages. The first three nymphal stages usually last 2-4 days each (this could, however, vary with temperature (De Barro *et al*., 2011). Fourth instar also called the 'puparium', which is measuring around 0.7 mm in length usually takes around 6 days within which it metamorphosed into the adult stage (Bellows *et al*., 1995: EPPO/CABI, 2018). Freshly produced eggs of *B. tabaci* are bright-yellow deposited by mature adults are placed on underneath the leaves, or the upper leaf surfaces when there are heavy infestations, on the pedicels as well which enclosed with the eggs, and later changed to dark-brown at hatching times (Cavalho and Oliveira, 2008). First stage of nymphs exist as oval in shape, whitish-yellow with two bright red eyes on the head (Morales and Anderson, 2007). Whiteflies are commonly situated on the leaves undersides that easily fly away immediately the plants are disturbed, the females always choose to place the eggs on the fresh, apex foliage, with the nymphs distributed according to their age vertically on the host plant, with the older stages habitually seen on the old and lower leaves (Brown and Idris, 2005; Li *et al*., 2022).

Emerging crawlers lost their legs at the first moult, excreting abundant quantities of honeydew during their feeding stages and at a temperature of 30°C the insect can complete its life cycle is in 17 days, but in the field growth and prolificacy differ according to host plants available and season, which could last for between 25-70 days (Naranjo aaand Flint, 1995). Females live for a fortnight in summer but could take many months in wintertime, laying between 80-300 eggs. Both legs and antennae are lost after the first moult and subsequent nymphal instars remain fixed to the leaf surface and have a scale like an appearance, with the last nymphal instar often called the pupa or the red-eyed nymph is the easiest to identify (Basu, 1995).

Adult whitefly suffers substantial mortality rates at a temperature lower than 12°C, the insect is spread by wandering storms between plants in the field for long distances (Morales and Anderson, 2007). Whitefly is a multivoltine (produces many generations within a year), it is a hemimetabolous insect that passes six stages in life from egg that hatched and pass through four nymphal instars before turning into an adult (Freeman *et al.*, 2001). A whitefly female can reproduce with or without mating (arrhenotokous parthenogenesis) and lays up to 400 eggs, in the Middle East, the pest raises 10-15 annual generations, *B. tabaci* pest survival is inhibited by climatic influences (Morales and Anderson, 2007).

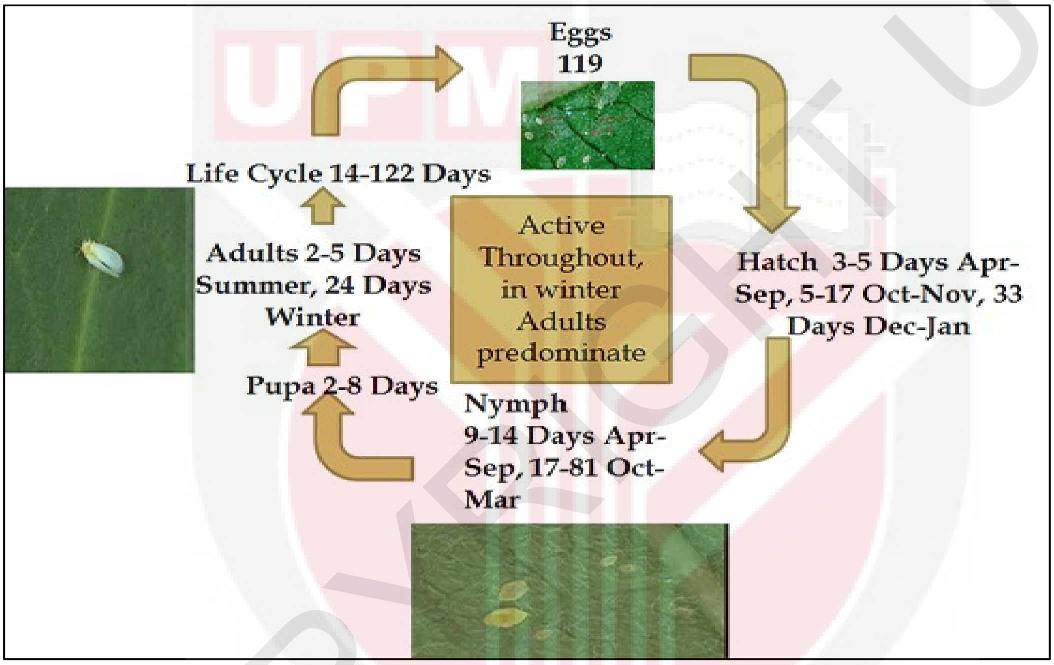

Figure 2.1 : Life Cycle of a Whitefly *B. tabaci*
(Source: Bellows *et al*., 1995)

2.8 Distribution of *Bemisia tabaci* in Africa

Whitefly, *Bemisia tabaci* is popularly known as a pest of field crops throughout the tropical and sub-tropical regions of Africa on cultivated crops such as` Tomatoes (*S. esculentum*), Cassava (*Manihot esculenta*), Cotton (*Gossypium*), Sweet potatoes (*Ipomoea batatas*), and Tobacco (*Nicotiana tabacum*) (Pakkianathan and Murad, 2014). Whitefly surveys conducted in West Africa used either morphological characteristics or electrophoresis patterns for identifying whitefly populations. The adult *B. tabaci* prevalent throughout Africa is the vector of different plant diseases such as the Cassava Mosaic Begomoviruses (CMBs) and Cassava Brown Streak Viruses (CBSVs) diseases that severely reduce cassava productivity in sub-Saharan Africa, causing economic losses of more than US$1 billion annually (Time *et al.*, 2020). In the late 1990s, CMD was rapidly spread by the whitefly vector through southern Uganda and into neighbouring countries in East Africa by the mid-2000s, 11 countries across East and Central Africa were affected by a severe CMD pandemic (Time *et al.,* 2020).

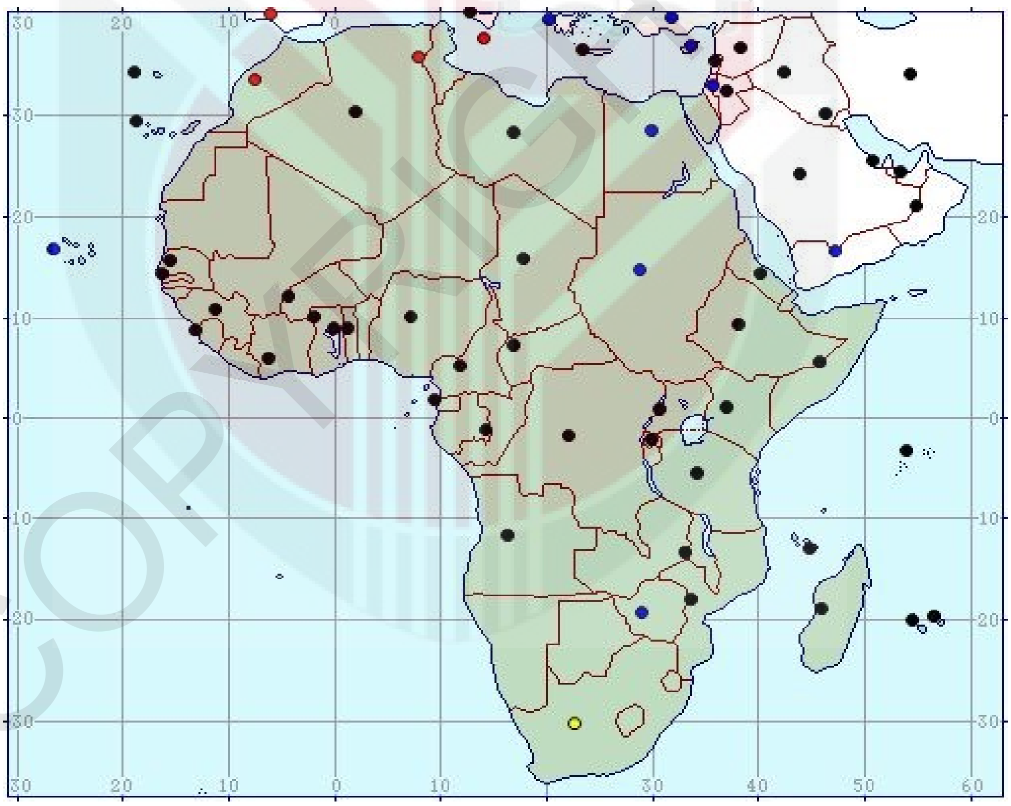

Figure 2.2 : Distribution of *B. tabaci* in Africa (Claire Beverley, CABI, Nosworthy Way, Wallingford, Oxon OX10 8DE, UK)

It was reported to be the first West African study to use mtCO1 sequences to investigate the multiplicity of *B*. *tabaci* in the region (Selvaraj and Ramesh (2012).

Out of 54 whitefly specimens used in the study, 20 originated from Ghana, Mali and Nigeria and the remainder came from Italy, Spain and Turkey, they identified three *B. tabaci* populations among specimens obtained from Sweet potato (*Ipomoea batatas* (L.) Lam), Okra (*Abelmoschus esculentus*), Cassava (*M. eculentus*) and Cowpea (*Vigna unguiculata* (L.) Walp), as reported by Fargette *et al*. (2006). However, the identification of the species involving genetic differences has only recently been attempted from Kenya in Africa (Abdullahi *et al*., 2017). In another study identified the cassava and the okra (*A. esculentus*) biotypes among similar whitefly populations in central and southern Coˆte d'Ivoire, which differed in their iso-enzyme electrophoresis patterns and host-plant preferences (Selvaraj and Ramesh (2012). The okra biotype was obtained from all the plant hosts they surveyed, except cassava (Sameena *et al*., 2019). Aheer *et al*. (2007), stated that *B. tabaci* biotype was only found on cassava and eggplant (*Solanum melongena* L.) in the study location. Omondi plant and on cassava including okra biotypes in Ghana using the same molecular methods and their results confirmed that the okra and cassava biotypes had the utmost preferences for okra as well as cassava (Sameena *et al*., 2019).

There are verified information on the *B. tabaci* species diversity in East Africa, while the situation in West Africa is relatively unknown in most of the countries in the region. Out of the sixteen countries in West Africa, *B. tabaci* survey reports are available only for Burkina Faso, Benin, Cote d'Ivoire, Liberia, Mali, Nigeria, Sierra Leone and Togo (Boyki and De Barro, 2014; Sameena *et al*., 2019). The International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, piloted the first detailed survey of whitefly populations in West Africa from 1976–1977 and reported annual and seasonal variations in whitefly population densities as reported in the work of

Selvaraj and Ramesh (2012), then surveyed whiteflies on cassava in Cote d'Ivoire and in 1995 a further study of *B. tabaci* populations in Coˆte d'Ivoire was published, where the number of whitefly adults caught on sticky traps situated in and around cassava plots was investigated and additional whitefly surveys were reported for Ghana, Benin and Nigeria. However, the first report of Whitefly in Nigeria was in 1993 and other West African part, it is possible that this insect occurred in West Africa much earlier than 1992 as was reported by Banjo (2013). While no information is available on the pest status of these insects in the study location creating a kwnoledge gap hence the need for this study.

Whitefly, *B. tabaci* has a wide host range both in the dry and wet seasons at Samaru, Nigeria and on a list of the host plants which are mostly perennial weed host such as *Ageratum conyzoides* L., *A. conyzoides*, *Sida* spp., *D. metel*, *D. stramonium*, *S. nigrum, Zinia elegans* Jacq., *Datura metel* D.C., *D. stramonium* L., *Solanum nigrum* L. and on other plants play an important role in harbouring whiteflies between crop plantings and some cultivated species (*Celosia argentea* L., *Carica papaya* L., *Cucumis* spp., *Telfaria occidentals* Hookf) in upland and lowland (Fadama and irrigated sites) in Nigeria are probably important reservoirs of *B. tabaci* during the dry season ((Ario *et al*., 2005; Time *et al*., 2020).

2.9 Abiotic Factors Affecting Arthropods

Insects are mainly affected by climatic factors like temperature, rainfall and relative humidity exhibiting strong positive correlation as reported by Thrivini (2019). These factors controlled the abundance of many insect pests including *B. tabaci* in different ecological zones of the world thereby giving a good predictive means of estimating, forecasting and controlling of insect pests in the field for an effective integrated pest management strategy. Abiotic factors like temperature, relative humidity and rainfall control the ecological interactions on insects that affect insect population in many ecological zones (Sing *et al*., 2011; Matilda *et al.,* 2012). Climatic factors such as temperature, relative humidity, rainfall, wind speed affect the status of insect pests, their population dynamics, abundance, distribution, feeding and insect behaviour, thus, affecting their physiology, immune responses including direct and indirect effect on prey and host relationship (Khalid *et al*., 2014). Other abiotic factors affecting the abundance and distribution of insect pests include soil types, topography, wind and proximity to water bodies (Mahmoud *et al*., 2002; Mansour *et al*., 2012).

Changes in the natural environmental conditions disrupt the arthropods with the passage of time, this includes the seasonal changes in conditions such as fluctuations in temperature, humidity, wind and rainfall stimulate their genetic potentials, rate of prolificacy, death rate, host range and consequently affect arthropod survival (Thrivini, 2019). Changes in wavelength of white light precisely for red and far-red light after absorbed by the photosynthetic system, shade avoidance are all among the abiotic factors affecting the survival, reproduction and population of insect pests in their natural environments (Khalid *et al*., 2014).

Climatic conditions largely affect the insect pest population and regulated their activity by either a direct or indirect way (Sevaraj and Ramesh, 2012). Similarly, Sharma *et al.* (2017), stated that weather factors such as temperature, relative humidity, wind speed and rainfall play vital role in determining the arthropod incidences, fecundity and development. This is because insect pest abundance and distribution changes with the change in abiotic factors with temperature been the most critical climatic factor influencing their growth and development that determine the interaction between pest activity and abiotic factors, this helps to produce predictive models aimed at forecasting pest incidence (Mathur *et al.*, 2012). Climatic conditions largely influence the pest numbers and activity as well as several predators and parasites either directly or indirectly (Arif *et al.*, 2006).

CHAPTER 3

ASSESSMENT OF MAJOR INSECT PESTS ATTACKING TOMATO CROP IN DRY AND RAINY SEASONS

3.1 Introduction

Insect pest problems are the major threats to agriculture that always cause serious losses thereby decreasing the economic and financial gains and destroying the agricultural produce all over the world. Protection against these insect pests is of paramount importance in order to ensure adequate foodsecurity and other agricultural products for a sustainable economic growth and development. Effective monitoring of these insect pests is therefore became very necessary. The main component of prevention of insect pests of crops in the field is through early monitoring and assessment of the time of abundance of these insects in the different seasons of the year.

Visual monitoring of insect pests in the field have been shown to be an effective and efficient monitoring method for identifying and determining insect species richness and abundance on a variety of cultivated and non-cultivated host plants including tomato (Ofori *et al*., 2014; Oyelade and Ayansola, 2015). One of the most common field insect population monitoring are manual counting method through the use of leaf turn method used for population monitoring of many pests (Yaobin *et al*., 2012). Additionally insect abundance is greatly influenced by abiotic factors such as temperature, relative humidity, wind and rainfall whose fluctuations result in increase or decrease in insect abundance across the world. Temperature is probably the most important environmental factor influencing insect behaviour, distribution, nutrition, phenology and role as disease vector (Mohd *et al*., 2009: Gupta, 2011).

Abiotic factors affect insect pest status and also affect insect population dynamics, distribution, abundance, intensity including feeding behaviour (Mathur *et al*., 2012: Khalid *et al*., 2014). Monitoring was targeted at different times of higher and cooler temperatures are directly and indirectly responsible for the abundance of the different insects found on tomato (Yumamura *et al*., 2006). This is because climatic factors such as temperature, relative humidity and rainfall can extend or reduce the life cycle of insects, affecting their growth and metabolic activities resulting to decrease or increase in abundance (Khan *et al.*, 2019).

Cooling and freezing temperature greatly destabilises the physiological, behavioural and mechanical activities of the different insect (Kumari and Kumar, 2017). Abiotic factors also play a key role in determining the abundance and dominance of a given pest complex, slow winds, low rainfall, low relative humidity, higher and low temperatures were found to favour insect pest build up (Thriveni, 2019). Insects generally respond to every deviation from the environmental conditions such as high or low temperatures, varied wavelength of light, rainfall intensity and fluctuating relative humidity (Salvaraj and Ramesh, 2012: Khalid *et al*., 2014; Sharma *et al*., 2017: Sameena *et al*., 2019).

The objective of the study is:

- to asses the relationship between the major insect pest abundance and climatic factors.

3.2 Materials and Methods

3.2.1 Study Site

These studies were conducted at the Kebbi State University of Science and Technology Teaching and Research Farm, Jega (Latitude 12° 11' N; Longitude 4^0 16' E), within the 2017 and 2018 dry and rainy seasons in the field. The area lies within the Sudan Savannah Agro-ecological zone of Nigeria, characterized by erratic and scanty rainfall that lasts for about 6 months. With a semi-arid climatic condition and average annual rainfall between 787.53-112.21mm. Having a relative humidity that ranges from 21-47% and 51-79% in the wet and dry spells, in that order. Temperature averages between 14-43^0C during the dry season and 27-41^0C during the rainy season (Eberibe *et al*., 2017).

Coordinates: (Latitude 12^{o} $11^{'}$ N; Longitude 4^{0} $16^{'}$ E)

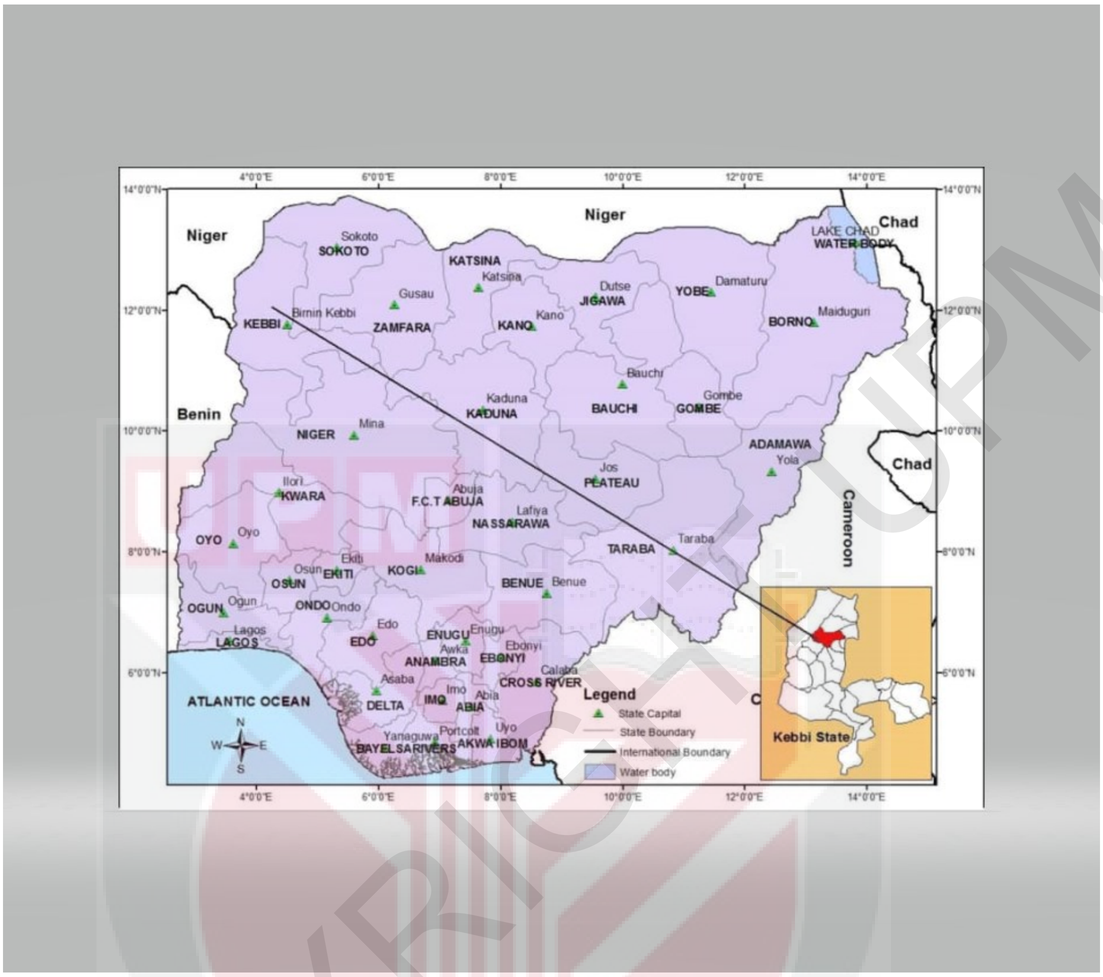

Figure 3.1 : Map of Jega Town in Kebbi State Nigeria

3.2.2 Cultural Practices, Nursery Management and Transplanting

Land clearing was performed by cutting and clearing of weeds from the experimental site, a tractor was used to plough the larger soil clods raised during harrowing to enhance moisture for plant growth. The land was then levelled by moving soil producing a gentle land slope for gravity flow to facilitate water flow. Tomato variety (Roma VFN) was obtained from the Kebbi Agricultural Supply Company (KASCOM). Seedlings were nursed in a nursery bed employing the nursery practices and techniques, transplanted at about 21 days after sowing. Sunken beds of 2 x 1 m were constructed, with the soil made into fine tilt after removing large stone stumps, irrigated using a watering can. Seeds were broadcasted in beds and mulched with millet stalk and watered. The soil was thoroughly mixed with farmyard manure at the rate of 4 tons per hectare. One week after germination the mulched material was gradually removed. Transplanted at 30-35 days post planting and transplanted in a row at a spacing of 40 cm intra and 60 cm inter row at 2 weeks after sowing and weeding was done when necessary (Muhammad and Singh, 2007).

3.2.3 Experimental Design

The farm consisted of four main plots represented as replications, with four sub-plot sizes of 4m x 3m (Area =12m^2) each, consisting of 5 rows per plot containing 10 plants per each row giving 50 plants population per plot spaced at 60x30 cm. Each Block is divided into four sub-plots replicated four times giving a total of 16 smaller plots containing 50 tomato plants each, giving rise to 200 plants per each Block (containing 4 smaller plots of 50 plants each). The four Blocks giving 800 tomato plants in each season in an open field, laid out in a Randomized Complete Block Design (RCBD). Data was obtained from each main plot from the 10 randomly selected plants giving a total of 200 plants per the four main plots (that is 4 Blocks) making a total of 800 plant population in each planting cycle as shown in Figure 2.4.

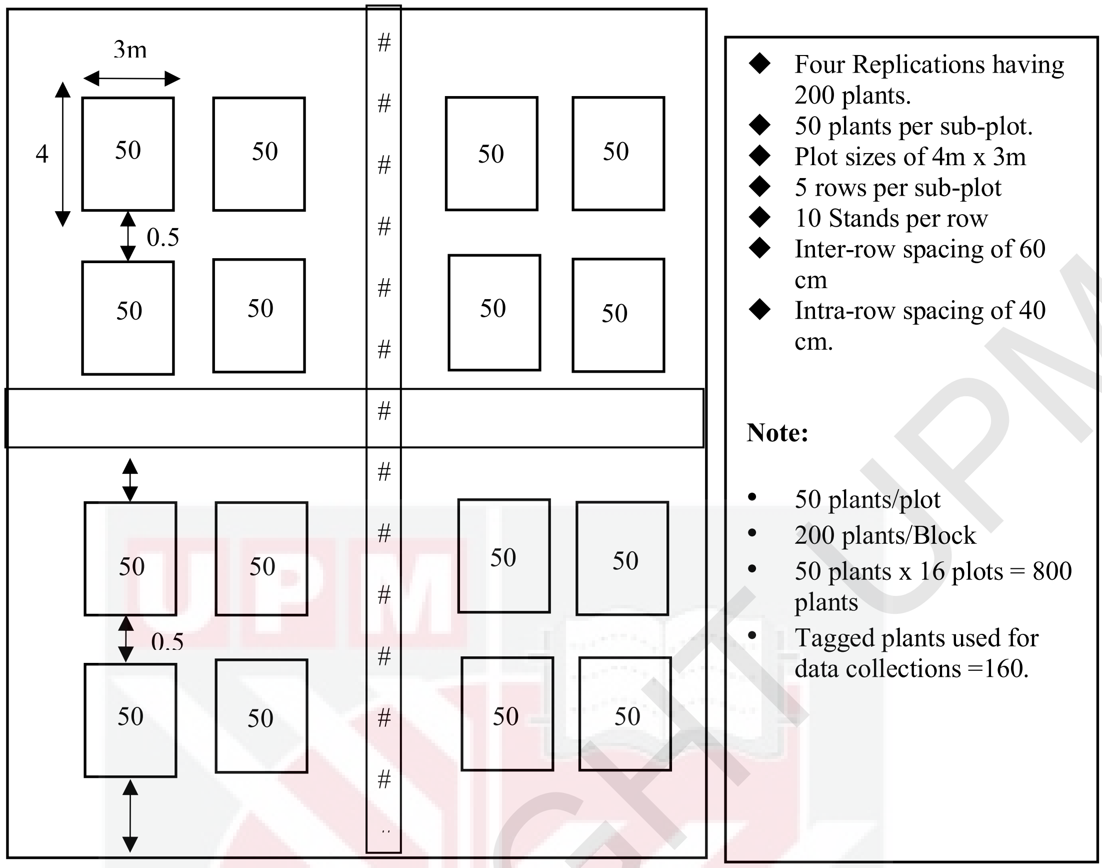

Figure 3.2 : Experimental Farm Layout at the Study Site

3.2.4 Fertilizer Application and Irrigation

Ten tons of cow dung per hectare and 150 kg urea, 60 kg SSP, and 50 kg Muriate of Potash (MP) per hectare applied at land preparation. Cow dung and the entire quantity of SSP and MP was applied during land preparation. Urea fertilizer broad caste in split applications after transplanting (Muhammad and Singh, 2014). Irrigation was carried out at intervals of two (2) days up to harvest in the dry season and whenever necessary in the rainy season.

3.2.5 Identification of Insect Pests

The different types of insect pests seen on tomato plant (Roma variety) were picked in the experimental field on tomato plants at two weeks after transplanting up to 12 weeks for two planting cycles (dry and rainy seasons) per each year. For identification the insect pests seen on tomato plants were visually sampled using hand picking method for bigger (more than 10.0 mm) and by using sweep net for smaller (less than 6.0 mm) ones with the aid of a Hand lenses. Sampled insects were transferred into separate plastic containers and stored in 70% ethanol and brought back to the National Insect Museum of Ahamadu Bello University, Zaria, Nigeria, where the sampled insects were identified using the Dichotomous Insect Taxonomic Keys (Zim and Cottam, 2000) which formed the basis for field identification.

3.2.6 Visual Insect Count

Sampling of the insect pests on tomato was performed by visual counting method adopted from Naranjo and Flint (1995). The exercise was performed in the early morning hours between 6:00–8:00 am when the insects were less mobile (Oparaeke *et al*., 2005). Sampling was performed weekly on Saturdays on 10 randomly selected and tagged tomato plants (per sub-plot) that gave 40 plants per Block (main plot) for insect counts using the leaf turn method. This gave a total of 160 randomly selected and tagged plant population used in each experiment performed twice a year (dry and rainy seasons). This commenced from two weeks after transplanting for 12 weeks (about 3 Months) during both dry and rainy seasons by counting the number of individuals insect pests seen on tomato plants in the research location.

3.2.7 Abiotic Factors

Climatic factors recorded during the study period were Temperature, Relative Humidity and Rainfall. These were obtained from the Meteorological Station of the

Faculty of Agriculture, Kebbi State University covering the periods of the two growing circles (dry and rainy seasons per each year in 2017 and 2018).

3.2.8 Data Analysis

Data generated were analyzed using a one way ANOVA for over all data on insect pest incidence in the study location and for insect counts in relation to dry and rainy seasons, using PROC GLM in SAS version 9.4 (SAS Institute Inc. 2014) suitable for Randomized Complete Block Design (RCBD) and significant means were separated using Least Significant Difference (LSD) at 5% significant level. The Pearson's correlation and regression analyses were also performed.

3.3 Results

3.3.1 Overall Insect Pests Identified and Their Mean Abundance on Tomato Plants during the Study Period in the Study Location

As presented in Table 3.1, the species *E. fabae* (Leafhopper) had the highest number in abundance (20459) in the dry (5948; 37.2%) and rainy (5362; 30.1%) seasons of the years 2017 and 2018. Indicating that *E. fabae* was the most prevalent insect pest species, than all others recorded on the tomato crop during the study period at the study location. Next to this in decreasing succession, were *M. euphorbiae* (Aphid) and *B. tabaci* (Whitefly), also recorded attacking the crop in both seasons of each of 2017 and 2018. In addition to this, *E. fabae* and *B. tabaci* were observed to have a numerically higher population in the dry season than that of the rainy season of both years. However, a contrasting occurrence was observed with *M. euphorbiae*, between the dry and rainy seasons of 2017 and that of 2018. Relative to these, *P. solenopsis* (Mealybug), *E. hirtipennis* (Flee beetle) and *H. armiger*a (Tomato Fruit worm) not only had the lowest record of abundance on tomato in the study area, but that all had higher mean population in the rainy season compared to that of the dry season of both years (Table 3.1).

Table 3.1 : Overall Insect Abundance in the Dry and Rainy Seasons of 2017 and 2018

Insect pest species	2017		2018		
	Dry season	**Rainy season**	**Dry season**	**Rainy season**	**Total**
E. fabae (Leafhopper)	5948 (37.2%)	5362 (30.1%)	5105 (40.9%)	4044 (33.9%)	20459
M. euphorbiae (Aphid)	5460 34.1(%)	2593 (14.6%)	2583 (20.7%)	5460 (32.4%)	16096
B. tabaci (Whitefly)	4025 (25.2%)	3289 (18.5%)	3482 (27.9%)	2476 (14.7%)	13272
P. solenopsis (Mealy bug)	143 (0.9%)	5114 (28.7%)	514 (4.1%)	2366 (14.0%)	8137
E. hirtipennis (Flee beetle)	257 (1.6%)	215 (11.9%)	226 (1.8%)	1285(7.6%)	1983
H. armigera (Fruit worm)	168 (1.1%)	1250 (7.0%)	556 (4.5%)	1223 (7.3%)	3197

Mean insect pest abundance according to seasons and years revealed significantly ($P<0.05$) higher insect pests recorded in the dry season of 2017 (Table 3.4). Revealing that more number of insects were recorded in the periods of dry season (27.18 ±2.53), significantly higher ($p<0.05$), that of the rainy season abundance (21.13±2.14) in 2017. In contrasts insect abundance in the dry (20.27±2.06) and rainy (19.17±1.76) season in 2018 did not significantly differ ($P<0.05$) indicating similar abundance in both the two different seasons of 2018 (Table 3.2).

Table 3.2 : Field Insect Pest Abundance as Affected by Seasons in 2017 and 2018

Season	**Mean abundance in 2017** ± S.E	**Mean abundance in 2018** ± S.E
Rainy season	21.13±2.14b	19.17±1.76 a
Dry season	27.18±2.53a	20.27±2.06a

Note: Means with similar letter(s) within column are not significantly different using LSD = Least Significant Difference at p=0.05 level of Probability.

Results in Table 3.3 below shows individual insect pest abundance obtained during the dry and rainy seasons of both 2017 and 2018 had revealed different outcomes.

There was a significant differences ($p<0.05$) in the number of individuals obtained between species in dry and rainy season in both years. Leaf hopper *E. fabae* was significantly the highest in abundance in both dry (31.00) and rainy (28.44) rainy seasons of 2017. Aphid *M. euphorbiae* was the second highest in the dry (28.42) and rainy (13.52) seasons of 2017. With Whitefly *B. tabaci* during the dry (26.76) and rainy (14.50) seasons recorded as the third most abundant insect pest on tomato in the study area during the study. However, the abundance of Mealy bug *P. solenopsis,* fruit worm *H. armigera* and Flea Beetle *E. hirtipennis* were significantly lower in abundance compared to the first three species (*E. fabae, M. euphorbiae* and *B. tabaci*). During the dry season of 2017, the abundance of Fruit Worm *H. armigera* (1.27) and Flea Beetle *E. hirtipennis* (1.20). Flea Beetle *E. hirtipennis* abundance in the dry (1.10) and rainy (1.20) seasons was significantly lower in abundance to all the other insect pests abundance monitored on tomato in the dry and rainy seasons of 2017 (Table 3.3).

Table 3.3 : Abundance of Insect Pest Species on Tomato in the Rainy Season of 2017

Insect species	Dry season	Rainy season
Leafhopper *E. fabae*	31.00 ± 2.11^{a}	28.44 ± 1.86^{a}
Aphid *M. euphorbiae*	28.42 ± 1.86^{b}	13.52 ± 0.57^{b}
Whitefly *B. tabaci*	26.76 ± 2.02^{a}	14.50 ± 0.55^{b}
Mealy Bug *P. solenopsi*	2.69 ± 1.36^{d}	9.30 ± 0.38^{c}
Fruit Worm *H. armigera*	6.51 ± 1.51^{c}	1.27 ± 0.08^{d}
Flea Beetle *E. hirtipennis*	1.10 ± 0.08^{e}	1.20 ± 0.05^{d}

Note: Means with similar letter within same column are not significantly different using LSD = Least Significant Difference at p=0.05 level of Probability.

The seasonal abundance of the insect pests monitored on tomato in the 2018 dry and rainy seasons revealed a similar trend to that of the 2017 abundance except on Aphid whose abundance was higher in the rainy season of 2018 than the dry season abundance. Results revealed that *E. fabae* in both dry (22.45) and rainy (20.18) was significantly higher in abundance than all the insect pests recorded on tomato in this study. In the dry and rainy season Aphid and Whitefly recorded similar abundance in 2018. However, more *P. solenops* and *E. hirtipennis* were recorded in the rainy season of 2018 than in the dry season of the same year. A contrasting result was obtained on *H. armigera* abundance showing higher abundance in the dry season than in the rainy season. Result indicated *E. hirtipennis* been significantly lower than all the insects pests found on tomato during the dry (1.41) and rainy (3.87) seasons depicting more abundance in the rainy season of 2018 (Table 3.4).

Table 3.4 : Abundance of Insect Pest Species on Tomato in the Rainy Season of 2018

Insect species	Dry season	Rainy season
Leafhopper *E. fabae*	22.45±2.02[a]	20.18±2.06[a]
Aphid *M. euphorbiae*	19.11±1.29[b]	17.73±1.57[b]
Whitefly *B. tabaci*	17.76±1.56[b]	15.66±1.12[b]
Mealy Bug *P. solenopsi*	2.69±0.72[d]	12.30±1.07[c]
Fruit Worm *H. armigera*	3.81±1.08[c]	4.88±1.48[d]
Flea Beetle *E. hirtipennis*	1.41±0.50[e]	3.87±1.22[d]

Note: Means with similar letter(s) within column are not significantly different using LSD = Least Significant Difference at p=0.05 level of Probability.

3.4 Relationship between Abiotic Factors and Insect Pest Abundance in Tomato during the Dry Seasons of 2017 and 2018

The result for correlation analysis between the three abiotic factors (temperature, relative and humidity) with the six insect pest species abundance in the dry seasons of 2017 and 2018. Correlation matrix shows a highly significant (P<0.05) positive correlation existed beween the variables namely; temperature and the relative humidity had significantly influences the abundance of the six insect pests monitored on tomato with the exception of few that correlated negatively. Results indicated that temperature and the relative humidity had significant positive correlationships in the dry seasons of both 2017 and 2018, by significantly favouring higher insect pest abundance on tomato in the dry seasons. Results depicted varying levels of positive relationships between the insect abundance and the two climatic factors. Hoever, significant negative relatonships also resulted between temperature and *E. hirtipennis* abundance (-0.744) and on the abundance of *H. armigera* (-0.465) in the dry season of 2017 and also between *H. armigera* (-0.488) and temperature and between *H. armigera* (-0.436) the relative humidity in the dry season of 2018 as shown in Table 3.5.

Table 3.5 : Relationship of Temperature and Relative Humidity towards the Abundance of Insect Pests in the Dry Seasons of 2017 and 2018

Insect pest species	Abiotic factors	2017		2018	
		R^2	r	R^2	R
M. euphorbiae (Aphid)	Temperature	0.635	0.797*	0.643	0.804*
	R. Humidity	0.456	0.673*	0.561	0.749*
E. fabae (Leafhopper)	Temperature	0.605	0.778*	0.523	0.723*
	R. Humidity	0.399	0.632*	0.634	0.796*
B. tabaci (Whitefly)	Temperature	0.711	0.711*	0.552	0.743*
	R. Humidity	0.668	0.668*	0.623	0.790*
E. hirtipennis (Beetle)	Temperature	0.554	-0.744*	0.658	0.811*
	R. Humidity	0.388	0.623*	0.543	0.737*
P. solenopsi (Mealy Bug)	Temperature	0.490	0.700*	0.231	0.481
	R. Humidity	0.551	0.551*	0.175	0.419
H. armigera (Fruit worm)	Temperature	0.348	0.589*	0.238	-0.488
	R. Humidity	0.217	-0.465	0.190	-0.436

Note: Significant at P<0.05

3.5 Relationship between Abiotic Factors and Insect Pest Abundance in Tomato during Rainy Seasons of 2017 and 2018

Table 3.6 showed the 2017 and 2018 rainy season insect abundance in the study area on tomato in relation to the temperature, relative humidity and rainfall. Correlation resulted in significant positive relationships of varying degrees indicating that all the three small bodied insects (*E.fabae, M.euphorbiae* and *B. tabaci*) monitored had positive relationships wit the temperature and relative humidity in the rainy seasosn of both 2017 and 2018, but had negative relationships with rainfall in both years depicting a significant reduction in the abundance of these small bodied insects in the rainy seasons on tomato. The three moderately bigger sized insect pests (*P.solenopsis, E. hirtipennis* and *H. armigera*) of tomato monitored in the rainy seasons of 2017 and 2018 had favourable significant relationships with both temperature, relative humidity and rainfall in both years with an exception in *E. hirtipennis* abundance (-0.587) during the rainy season of 2017 which had a significant negative relationship with rainfall. Results indicated that the more the rainfall the lesser the smaller body insect pests of tomato and the more the abundance of the moderately bigger size insect pests of tomato in the study location as shown in Table 3.6.

Table 3.6 : Relationship of Temperature and Relative Humidity towards the Abundance of Insect Pests in the Rainy Seasons of 2017 and 2018

Insect pest species	Abiotic factors	2017		2018	
		R^2	r	R^2	R
M.euphorbiae (Aphid)	Temperature	0.559	0.748*	0.299	0.599
	R. Humidity	0.498	0.650*	0.218	0.468
	Rainfall	0.711	-0.843	0.711	-0.843*
E.fabae (Leafhopper)	Temperature	0.622	0.789*	0.622	0.789*
	R. Humidity	0.477	0.691*	0.477	0.687*
	Rainfall	0.822	-0.927*	0.822	-0.907*
B.tabaci (Whitefly)	Temperature	0.711	0.849*	0.711	0.849*
	R. Humidity	0.497	0.705*	0.497	0.705*
	Rainfall	0.655	-0.809	0.655	-0.809
E.hirtipennis(Flee Beetle)	Temperature	0.441	0.664*	0.761	0.872*
	R. Humidity	0.399	0.632*	0.442	0.666*
	Rainfall	0.344	-0.587*	0.665	0.816*
P.solenopsis(Mealy Bug)	Temperature	0.551	0.743*	0.577	0.757*
	R. Humidity	0.448	0.670*	0.551	0.742*
	Rainfall	0.397	0.631*	0.443	0.665*
H.armigera (Fruit worm)	Temperature	0.712	0.844*	0.289	0.537*
	R. Humidity	0.601	0.775*	0.200	0.447
	Rainfall	0.669	0.836*	0.655	-0.810*

Note: * Significant at $p< 0.05$

The results for simple linear regression analysis produced the equation for the description of the relationship between the factors and the responce variables; $Y=0.479x + 19.661$, $R^2 = 0.748$ for temperature in the dry seasons of 2017 and 2018, $Y = 0.468x + 18.659$, $R^2 = 0.714$ for temperature in the rainy seasons of 2017 and 2018. $Y = 0.414x + 4.059$, $R^2 = 0.988$ for relative humidity in the dry seasons of 2017 and 2018. $Y = 0.679x + 1.670$, $R^2 = 0.9965$ and $Y = 0.691x + 4.113$, $R^2 = 0.565$ (Appendix D1-D5).

3.6 Discussion

The effects of climatic factors; temperature, relative humidity on the abundance of the six insect pests of tomato monitored favoured higher abundance of the tree small body-size insect (*E. fabae, M. euphorbiae* and *B. tabaci*) by influencing, dictating and determining their physical and physiological activities of the insect larvae and adults, insect movements, phenology and period of development and ability to endure severe weather factors that determining insect population with rainfall been very suppressive to thee smaller sized insects as strongly supported by the findings of Sanjeeb *et al*. (2019). Temperature and relative humidity influenced both the insect abundance as well as favourable relationships in the dry seasons with the large body sized insects (*E. hirtipennis, P.* solenopsis and *H. armigera*) monitored. Higher higher abundance of insect pests on tomato obtained in this study temperatures may likely be attributed to the higher temperatures because temperature and body weight of an insect are the most prominent determinants of metabolism, development, reproduction, population growth and species diversity, as reported by Wade (2020), temperature and the relative humidity had positive significant effect on the abundance of *B. tabaci* on tomato. This study is further supported by the findings of Khan *et al*. (2019), who stated that abiotic factors such as average temperature and average relative humidity had a strong positive and linear relationship with the abundance of *B. tabaci* on tomato.

Weather factors like temperature and relative humidity, mainly encourage insect population growth or lead to reduction in population, during the warm and dry weather where these insect activities increased significantly as observed in this study. Similarly, the outcome of this study shows that temperature and relative humidity favoured the highest insect pest abundance during the dry season. Abiotic factors regulate insect population which are responsible for many physiological and enzymatic activities in insects bodies (Khan *et al.,* 2019). Temperature was found to be the major climatic factor playing the role of determining insect abundance, with relative humidity having direct and indirect impact on insect growth, development, survival, behaviour, reproduction and population ecology of insects as key players in insect abundance (Zeshwan *et al*., 2015). In a related study, temperature was reported to be the dynamic driving power behind insect development, growth and behavior and this is because insects are poikilothermic ("cold-blooded"); meaning they are not capable of regulating their outside body temperature and internal temperatures varying with the ambient environmental temperature (Sanjeeb *et al*., 2019). This study revealed dry season as the most conducive period for insect fecundity, growth, development and highest abundance due to the complete absence of rainfall that significantly reduces insect pest abundance.

Insect abundance in the rainy season depicted that a rise in temperature and humidity also led to increase in insect abundance in the rainy seasons, while an increase in rainfall led to decrease in *E. fabae, M. euphorbiae and B. tabaci* abundance throughout the study period. This is likely attributed to the roles of abiotic factors in the regulation of insect abundance as a result of several physiological and biological peculiarities influenced by temperature, relative humidity and rainfall which regulate the ecology of insect communities in an area. This results is also in agreement with the earlier findings of Mathur *et al*., 2012: Mailafiya *et al*., 2014: Degri and Sani, 2015 and Wade *et al*. (2020) who stated that tomato pests such as whitefly (*B. tabaci*), Aphids (*Aphis gossypii*) Leaf miner (*Liriomyza trifolii*), Leaf hopper (*Amrasca binguttula binguttula*) and Fruit worm (*Helicoverpa armigera*) were observed to be the major insect pests of tomato as influenced by the climatic factors prominent of which are temperature, humidity, rainfall and wind.

Abundance of *P. solenopsis*, *H. armigera* and *E. hirtipennis* in this study as influenced were greatly influenced by the climatic factors that depicted similar with the findings of Mathur *et al*. (2012), that relative humidity, rainfall and temperature are the chief weather parameters that largely dictate the rates of growth and development of insect pest. In a similar findings by Chavan *et al*. (2013), it was revealed that insect pest abundance are directly influenced by weather factors such as temperature, relative humidity and rainfall. Similarly, Mathur *et al.* (2012), also reported that seasonal insect abundance is greatly influenced by abiotic factors such as rainfall and temperature that influenced Leaf hoppers incidence including *B. tabaci* and Fruit worm abundance on *Solanum melongena*. Insect pest abundance was found to be considerably subjective to abiotic factors such as environmental temperature, average weekly relative humidity including average weekly rainfall during the study period, this is further supported by the works of Thriveni (2019), who found out that local weather patterns have significant impact on the abundance of insect pests in crops with rainfall severely affecting their abundance.

Results in this study shows that rainfall was greatly unfavourable to the abundance and survival of the smaller sized insects and this was strongly surpported by the studies conducted by Sharma *et al.* (2017), they also revealed that rainfall is an antagonist that reduce many insect population in an ecology, further stating that heavy rainfall dislodges smaller sized insects from plant parts and leading to cooling effect on the environmental temperature that negatively affect insect metabolism thereby reducing their abundance in the environment. In a related reseach by Aheer *et al*. (2007), futher reported that Aphid population changes are mostly reliant on temperature as well as relative humidity, but negatively (r = -0.799) associated with rainfall. The interaction of temperature changes with increase or a decrease in rainfall and humidity grossly influencing the growth, development and survival of the insect pest thereby affecting their abundance on tomato in the field. The interaction of temperature changes with increase or a decrease in rainfall and humidity grossly influencing the growth, development and survival of the insect pest thereby affecting their abundance on tomato in the field. In multi climatic factors especially temperature can reduce or increase the longevity and fecundity of insects in the environment. When it rains heavily, many small insects get dislodged from plant surfaces by the combined effect of wetness and the kinetic energy of the rain drops as well as strong winds. The inverse relationship between whitefly population with rainfall in the rainy season could be attributed to the unfavourably lower humidity rates and the physical beating effects of rainfall that kills the insect pest in the wet period. The orientation of the leaves on the plant and consequently the position of the insect on the plant would be criticall as it exposes the insects to to heavy and detrimental rain drops. Similarly, Mahmood *et al*. (2002), greed with this study and stated that lowest as well as highest temperature increased Leafhopper abundance, and agreed with this results that rainfall correlated negatively with the Leafhopper abundance on Brinjal plant, while in contrast to the work of Cavalho and Olievera (2015), that average and minimum temperatures and rainfall did not correlate with *Empoasca sp.* abundance throughout their study period. Results from this study on the relationship between the small body size insect population and rainfall of 2018 showed inverse relationships with the abundance of *B. tabaci, E. fabae* and *M. euphorbiae* strongly agreed with the findings of Ohnesorge *et al*. (1981), who stated that the oviposition by smaller insects such as *B. tabaci* was impaired by rain as it led to a drastic reduction of its population. Sharma *et al*. (2017), stated that average humidity as well as precipitation rates indicated an unfavourable relationship on *B. tabaci* population in the field. In a similar work by, Ario *et al.* (2005), they found that whitefly population increased in September and October and correlated with higher relative humidity (80-90%) and increasing temperature (36-38º C) as these favouring the development of the immature stages of *B. tabaci* by shortening the period of each stage. Result obtained on the relative humidity in rainy season is supported by the findings of Time *et al*., (2020), who stated that low humidity is the major mortality factor on whitefly in Israel, leading to the cessation of oviposition and resulting to high adult mortality. In a related research low humidity of 20 % or less during hot weather has been reported to be highly detrimental to the immature stages of insects such as whitefly during the rainy season and its activity decreases with the onset of rainy season as heavy rains were usually followed by a drop in population levels. This is likely due to the un-favourable conditions such as heavy raindrops and cooler temperatures that negatively affect developmental stages and growth of whitefly in rainy seasons. This result is further supported by Sharma *et al*. (2017), who found that humidity and rainfall correlated negatively with the whitefly population.

Temperature favoured the abundance of most of the insect pests monitored on tomato in this study where temperature correlated significantly positive with the abundance of the insect pests monitored with the exception of rainfall that led to significant reduction of *B. tabaci* abundance, *E. fabae* including *M. euphorbiae* abundance that had signifcant negative relationships. However, in contrast to this result Khalid *et al.* (2014), reported that overall reproduction, oviposition time and insect longevity were reduced and pre-oviposition time was positively correlated to increase in temperature. The significant roles played by temperature leading to fluctuations of heat, cooling and freezing that greatly affect the behavioral, mechanical, biochemical and physiological activities of many insects as supported by Thriveni (2019). Showeing significant correlation with both temperature, relative humidity in the dry seasons recorded positive relationships with insect abundance in the rainy season of 2018, this can likely be attributed to the role played by environmental temperature which substantially facilitates fecundity as well as the growth rate of the insect monitored in this study clearly indicating the influence of temperature in the natural regulations of insect pest abundance in the environment. This result also agreed with the findings of Matilda *et al*. (2012) and Shakeel *et al.* (2015) added that insects such as Aphid suffers population decreases as the maximum temperature increased, and the minimum temperature showed a significant, but negative correlation with pest population. Similarly, Gerling *et al.* (2001), found out that whitefly developmental threshold were subjected by temperature ranges of between of 11 and 33º C. Schowalker (2000) stated that insect population can fluctuate considerably over time if environmental conditions change in a way that favours insect population growth, the population will increase until when other regulatory factors reduce or stop their population growth rate. In a related study in Sudan, Sanjeeb *et al.* (2019) also reported a sharp increase in whitefly population in September and October which was directly correlated with higher relative humidity (80-90%) and increasing temperature (36-38 ºC).

The strong positive relationship between temperature and *B. tabaci* and other insects throughout the dry sseason from this study could likely be attributed to the conducive environment that promoted fecundity and faster progress as well as the development of the pest as against the favourable conditions during the dry season period that favours the different stages of growth of insect pets in the field specifically the smaller body sized ones. Findings from this study corroborate with the work by Mohd. *et al.* (2009), who reported that whitefly population start increasing and reached the highest abundance at reproductive stages as a result of increased availability of food particularly with an increasing trend of temperature that increased the activity of whitefly and increased infestation during its growth stages in dry seasons when rainfall is absent. directly and indirectly affect insects through dictating and determining the activity of larvae and adults, insects movements, phenology and developmental period, including the probability of enduring in antagonistic climatic situations determining population. Incidental impact of weather factors comprises of the climatic influence on environment hosting the insects indicating the local weather patterns having significant impact on the abundance of insect pests in our crops.

This finding is also in line with the findings of Chakraborty and Deb (2011), who reported that high relative humidity and shady areas of the field encouraged growth insects in rainy seasons. This study confirmed that climatic factors exert a great influence on the growth, development, distribution, and changes in pest abundance in addition to the biotic influences stand very vital in affecting disparities on abundance of insect (Selvaraj and Ramesh, 2012). However, Radonjic and Hrncic (2017), also reported that temperature and precipitation are among the most powerful factors that affect the biology, behaviour, abundance and distribution of insects such as Flea beetles (*Luperomorpha xanthodera*) in China, Europe and Mediterranean region. Furthermore, results obtained in this research on *H. armigera* abundance correlated with temperature, relative humidity as well as rainfall in this research tallies with the work of Ceceilia *et al*. (2013), who stated that changes in population size of some insects have been linked openly to changes in climatic factors, because the average humidity, precipitation, wind rate and temperature are the major climate parameters that generally coordinate the action of a given type of insect. Rainfall, temperature and other weather factors cause seasonal fluctuation and are important regulating factors of many tropical insects (Shakeel *et al*., 2015). Similar results was obtained on subjecting the data to a regression analiysis which indicated that the influence of the three climatic factors significantly influenced the presence or absence of the six insects monitored on tomato plants in both dry and rainy seasons throughout the experimental periods in thi study. Regression analysis was significant an the separate equations were predicted to account for the relationship between the climatic factors and the response variables produced favourable equations that will fill the models with significant coefficients of determination.

3.7 Conclusion

The present investigation has indicated variable abundance of the six different insect pests monitored and recorded on tomato plants in the field that were identified and studied during both dry and rainy seasons of 2017 and 2018 in the study location. The major insect pests of tomato monitored in the study field were recorded and studied in this research were; Potato Leafhopper - *Empoasca fabae,* Tomato Aphid - *Macrosiphum euphorbiae*, Silverleaf Whitefly - *B. tabaci,* Tomato Fruit worm - *Helicoverpa armigera*, Tobacco Flea Beetle - *Epitrix hirtipennis*, and Tomato Mealy bug - *Phenacoccus solenopsis*. These insect pests were found to attack tomato plant in the study field that showed different abundance in the dry and rainy seasons.

The highest mean weekly number of small body sized insects were recorded in the dry season than rainy season among the major insects monitored as the heavy rains is detrimental to them by reducing their abundance. While the bigger sized insect pests monitored were significantly higher in abundance in the rainy seasons of both seasons. Abiotic factors; temperature, relative humidity and rainfall played major roles in the regulation of the insect pest abundance that correlated with the pest population in the two seasons. Leafhopper (*E. fabae*). Whitefly (*B. tabaci*) and Aphid (*M. euphorbiae*) were the most abundant among all the insect pests monitored on tomato in the study field throughout the dry and rainy periods. Whitefly is considered as the most destructive among the insect pests on tomato which is strongly supported by the findings of Sanjeeb *et al.* (2019), as the damages it caused on plants like tomato are largely through vectoring of the most deadly disease-causing viruses on tomato. This research revealed that tomato plant suffer higher attacks when insect pest attacks particularly *B. tabaci* population observed to be highest at the onset of the dry seasons at the research location. The findings in this study also revealed the time of highest insect abundance on tomato in the study area which will significantly assist in the effective planning and management of these insect pest control strategies on tomato production. The detrimental effects of insect abundance on the growing tomato is determined by different factors among which are climatic factors (Solomon *et al.*, 2014). In this research *B. tabaci* abundance was studied in relation to the three climatic factors namely; atmospheric temperature, relative humidity and average weekly rainfall that affect its abundance in the two different seasons.

CHAPTER 4

Bemisia tabaci ABUNDANCE ON TOMATO AS AFFECTED BY ABIOTIC FACTORS

4.1 Introduction

The study will investigate the relationship between the climatic variables and whitefly abundance as they effect the growing tomato plants in the study farm for the different seasons using the Yelloe Sticky Traps to monitor the *B. tabaci* abundance in the field. Results in Chapter 3 show that the abundance of the insect pests including *B. tabaci* monitored on tomato were greatly influenced by increased or decrease in the rates and intensity of these abiotic factors; temperature, relative humidity and rainfall having either positive or negative relationship leading to a population build up or decrease (Umar *et al*., 2003). Whitefly develop rapidly during warm weather which is higher in the dry seasons in the study area, encouraging population build up as a result of favourable and conducive conditions (Ugunna *et al*., 2015). These factors were responsible for *Bemisia tabaci* activity, abundance and fecundity including the natural enemies, host plants and the immediate surrounding environment (Sivani *et al*., 2020). *B. tabaci* been the main vector of viral diseases of tomato is considered as the most destructive insect of tomato among the six insects pets found on tomato in the location. However temperature and relative humidity are the most crucial weather elements that dictate the growth, development and abundance of *B. tabaci* throughout the seasons (Kumari and Kumar, 2017). *Bemisia tabaci* grow and developed quickly during warm weather in conditions where natural enemies are annihilated leading to high fecundity, abundance and distribution. Among the meteorological parameters temperature was the most crucial factor affecting the physiological, physical and biological processes governing insect life, growth and development (Fishpool *et al*., 2009). However, relative humidity and temperature mainly dictate insect activities of different species, as they interact together in the ecosystem to greatly influence the different biological organisms such as insects and the crops. Depending on location the relative humidity and temperature relate positive or negatively with *B. tabaci* leading to an increase or decrease in its abundance (Time *et al*., 2020). These weather parameters like temperature, relative humidity and rainfall greatly affect the distribution, abundance and degree of infestation of *B. tabaci* in both the environment and on the cultivated plants (Kumari and Kumar, 2017). Heavy rainfall is detrimental to *B. tabaci* particularly on the nymphal stages as the physical hitting effects of the rain drops destroy them leading to a substantial decrease in their population (Alim *et al*., 2017: Time *et al*., 2020).

The population of *B. tabaci* is governed by changes in temperature at a particular time in a given environment, unfavourable lower or higher temperature levels lead to decrease in population because the *B. tabaci* immature stages are faced with desiccation with a relatively high temperature regimes in the field (Thriveni, 2019; Khan, 2019; Zeshwan *et al.* (2015). It is well researched and documented that abiotic factors such as temperature, relative humidity and rainfall control the ecological interactions on insects that affect insect population in many ecological zones (Matilda *et al.,* 2012). However there is scanty report on information concerning the diversity and distribution of these economic insect pest species (Oyelade and Ayansola, 2015) in the specific studied area. The average temperature of the study location is 37.5 ºC, with a maximum temperature of 41.1 ºC and a minimum temperature of 15 ºC. With a maximum relative humidity of 87.5% and a minimum of 10%. Having an average rainfall of 358 mm.

Therefore the objective of this study was to investigate the *B. tabaci* abundance on tomato plants in relation to climatic factors in the study area.

4.2 Material and Methods

4.2.1 Plot Layout and Research Design

Roma tomato variety was planted in sub plots sizes of 3mx 4m (12 m^2) giving a total of 16 smaller plots, consisting of 5 rows per plot containing 10 plants per each row giving 50 plants population per plot spaced at 60x30 cm, laid out in a Randomized Complete Block Design (RCBD) replicated four times. Data was obtained from each main plot from 20 rows (on the 5 plants each per sub-plot) giving the total of 200 plants per the four main plots randomly chosen for insect monitoring.

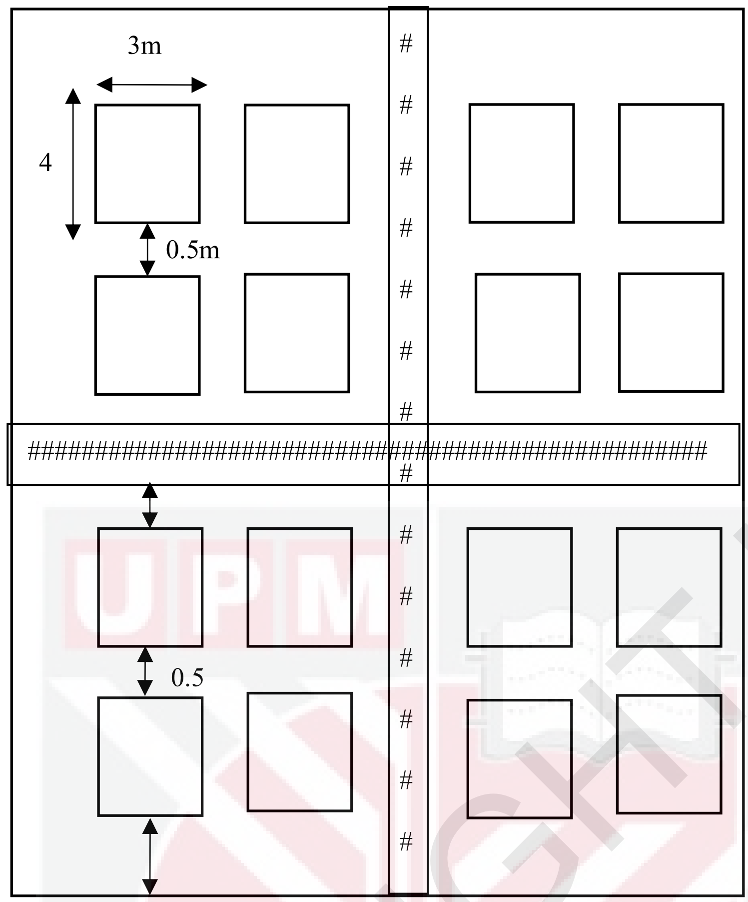

Figure 4.1 : The Experimental Farm Layout

With Plot sizes of 4m x 3m, having 5 rows per sub-plot with 10 stands per row giving a total of 50 plants per sub-plot. With an inter-row spacing of 60 cm intra-row spacing of 30 cm.

4.3 Planting

Certified seeds of tomato cultivar Roma was acquired at the Kebbi State Agricultural Company, in Birnin-Kebbi. Seedlings were raised in nursery beds employing the nursery management techniques and transplanted at about 30-35 day after sowing.

4.4 Data Collection

The experiment was conducted in the University Farm, Jega (Latitude 12^{o} $11^{'}$ N; Longitude 4^{0} $16^{'}$ E), Kebbi State, Nigeria, conducted in the dry and rainy seasons of 2017 and 2018 (in one planting circle per each season) to monitor the abundance of adult *B. tabaci* using the Yellow Sticky Traps (YST) sampling method adopted from Yaobin *et al*. (2012). Three rectangular pieces of sticky cards (16.5 x 21.5cm) painted with sticky non-toxic glue each per plot were placed at the recommended rate of one trap per 5 m^2 (Yaobin *et al*., 2012). The sticky traps painted with sticky non-toxic glue for capturing the flying insects employed for monitoring *B. tabaci* abundance and relative infestation levels in the field. Monitoring commenced one week after transplanting on a weekly basis and lasted for 12 weeks. Sticky cards were placed vertically on stakes 30 cm above the plant canopy (Razvi *et al*., 1999), to count the whitefly adults weekly, being sure to distinguish them from other small flying insects that may stick on the traps.

The sticky cards placed vertically to monitor and count the whitefly adults that are trapped on the cards weekly and according to the plot, being sure to distinguish them from other small flying insects that may stick on the traps (Gerling *et al*., 2001). Counts were recorded on a monitoring form to track population numbers and sticky cards replaced when fully covered by trapped insects. Counts were recorded on a monitoring form to track population numbers and sticky cards replaced when necessary (Devi and Roy, 2017).

4.4.1 Climatic Factors Recorded during the Study Period

The abiotic factors recorded in this experiment were; average Temperature, Relative Humidity and average Rainfall in the two seasons of 2017 and 2018 as obtained from the Meteorological Station of the Faculty of Agriculture, Kebbi State University, Nigeria.

4.5 Data Analysis

Data obtained on the adult *B. tabaci* counts all the Yellow Sticky Traps recorded from each plots were subjected to the Pearson's correlation analysis by Karl Pearson in 1948, using SAS Software version 9.4 (SAS Institute Inc. 2014).

4.6 Results

4.6.1 Relationship of *B. tabaci* Abundance with Climatic Factors in the Dry and Rainy Seasons of 2017

Temperature and relative humidity favoured higher abundance of *B. tabaci* throughout the periods of this study, with the exception of rainfall that led to significant reduction of the number of *B. tabaci* throughout the period under study. A significant correlation existed between the *B. tabaci* abundance and mean temperature including the relative humidity in 2017 indicating how environmental temperature determines *B. tabaci* population as a result of having effect on its physiology and Biology. *B. tabaci* abundance in both the dry season (r=0.686) and in the rainy (r=0.587) with temperature and relative humidity as depicted in Table 4.7. A positive relationship existed between temperature (r=0.550) and the relative humidity (r = 0.443) in the rainy season of 2017. However, a negative significant correlation resulted between *B.*

tabaci abundance and rainfall (r=-0.975) showing an adverse relationship that led to drsatic reduction in abundance in the rainy season of 2017 as shown in Table 4.1.

Table 4.1 : Relationship between *B. tabaci* Abundance and Climatic Factors in the Dry and Rainy Seasons of 2017

Season	Abiotic factors	R^2	Coefficient of Correlation (r)
Dry	Temperature	0.471	0.686*
	R. Humidity	0.344	0.587*
Rainy	Temperature	0.310	0.550*
	R. Humidity	0.179	0.443*
	Rainfall	0.951	-0.975*

* Significant at P < 0.05

4.6.2 Relationship of *B. tabaci* Abundance with Climatic Factors in the Dry and Rainy Seasons of 2018

Similar results to those of 2017 were obtained in 2018 depicting the significant roles played by climatic factors on *B. tabaci* abundance by affecting the growth, development and fecundity of this insect pest which exhibited positive significant correlation with mean weekly temperature as well as the relative humidity, with a negative significant correlation with rainfall which significantly (P < 0.05) reduced *B. tabaci* abundance in wet period. Mean temperature (r = 0.820) increase in abundance in the dry season of 2018. The average relative humidity (r = 0.771) had led to more *B. tabaci* abundance showing a significant correlation them in the dry season (Table 4.2). With similar results in wet season abundance where temperature (r = 0.736) as well as humidity contributed (r = 0.607) increases on *B. tabaci* abundance showing significant positive correlation with *B. tabaci* abundance in the rainy season of 2018. However, rainfall (-0.986) significantly decreased the abundance of *B. tabaci* as it related negatively with it abundance in the rainy season of 2018 as shown in Table 4.2.

Table 4.2 : Relationship between *B. tabaci* Abundance and Climatic Factors in the Dry and Rainy Seasons of 2018

Season	Abiotic factors	R^2	Coefficient of Correlation (r)
Dry	Temperature	0.674	0.820*
	R. Humidity	0.594	0.771*
Rainy	Temperature	0.541	0.736*
	R. Humidity	0.368	0.607*
	Rainfall	0.973	-0.986*

* Significant at P< 0.05

Results showed the favourable roles played by climatic factors on the abundance of *B. tabaci* abundance on tomato host in the study location as monitored. Simple linear regression analysis produced; varying responses between the *B. tabaci* abundance and the three climatic factors in the dry and rainy seasons giving the following equations; $Y = 0.713x + 7.231$, $R^2 = 0.927$ for temperature and *B. tabaci* abundance in the dry seasons of 2017 and 2018, $Y = 0.118x + 10.970$, $R^2 = 0.532$ for temperature and the rainy season abundance, $Y = 11.742x + 6.331$, $R^2 = 0.946$ for relative humidity and *B. tabaci* abundance in the dry seasons of 2017 and 2018, $Y = 0.743x – 6.231$, $R^2 = 0.914$ for the relative humidity and *B. tabaci* abundance in the rainy seasons of 2017 and 2018 and $Y = -0.103x + 18.333$, $R^2 = -0.925$ for rainfall and B. tabaci abundance in 2017 and 2018 (Appendix D6-D10).

4.7 Discussion

Correlation analysis between the mean weekly *B. tabaci* abundance with the climatic factors obtained in this study using the Yellow Sticky Traps indicated favourable relationships between *B. tabaci* with temperature and the relative humidity is in line with the results obtained by Singh (1990) and Tufail *et al*. (2017) maximum and minimum relative humidity and temperature correlate positive and significantly with the yellow sticky traps catches of sweet potato whitefly, they further reported that whitefly build-up increases when both temperature and relative humidity are high. It is likely as a result of the regulation of insect activities by these climatic factors, as stated by Sameena *et al*. (2019) and Matilda *et al*. (2012), that climatic factors regulate physiological and biological processes in the body of insects thereby influencing their abundance. This depicted the significant role played by temperature and relative humidity in the growth, development and abundance of *B. tabaci* monitored in both seasons in the study area. Showing that the higher the temperature and relative humidity the higher the *B. tabaci* abundance on tomato during both seasons. However, rainfall reduced *B. tabaci* abundance depicting that the higher the rainfall the lower the *B. tabaci* abundance, this is likely as a result of rainfall physically disrupting the activities, growth and development of *B. tabaci* likely as a result of damages it inflicts on the smaller insect like *B. tabaci*. This finding also agreed with the findings of Nagamandla *et al.* (2017), who stated that maximum, minimum temperature, maximum, minimum, average relative humidity, mean canopy temperature showed a significant positive correlation with *B. tabaci* population in open field. Similarly, rainfall correlated significantly negative with the whitefly abundance in the rainy season was also reported in other works. According to Kedar *et al*. (2014); Zanwar *et al*. (2014); Mehra and Krishna (2017), heavy rainfall unfavourably affected *B. tabaci* adult abundance and caused a significant reduction of its abundance in the study location.

Results on *B. tabaci* abundance with climatic factors in the dry and rainy seasons of 2018, revealed positive relationship through mean weekly temperature and relative humidity, and correlated negatively with rainfall which significantly reduced *B. tabaci* abundance in wet period using the yellow sticky traps. This result is also in agreement with the results of Berlinger *et al*. 2002; Yaobin *et al*., 2012, who stated that yellow traps remain frequently applied method in detecting the presence and abundance of insects like *B. tabaci*, leaf miners as well as aphids. Similarly, this finding also agreed with the works of Mohd *et al*., 2009 and Mansour *et al.* (2012), that variation in weather parameters such as average temperature, humidity as well as precipitation dictate the availability and pest abundance in a given area at a given time.

Early days of the dry season likely favoured more whitefly population than the rainy seasons as a result of the unfavourable conditions like physical effect of the raindrops that destroys all smaller soft-bodied insects such as aphids and temperature and relative humidity favoured more whitefly population as reported in the findings of Selvaraj and Ramesh (2012), Sharma *et al*. (2017) and Sameena *et al*. (2019). This study is only in line with the findings of Razvi *et al.* 1999; Yaobin *et al*. (2012) that yellow sticky traps are a commonly used method for population monitoring of many insect pest species such as *B. tabaci*, leaf miners, and aphids. Similarly, the present finding agreed with the works of Mohd *et al*. (2009) and Gu *et al.* (2020), that variation in weather parameters like temperature, relative humidity and rainfall dictate the availability and abundance of insect pests in a given area at a given time. This results is in agreement with the results obtained by Shah *et al.* (2002), maximum and minimum relative humidity and temperature correlate positive and significantly with the yellow sticky traps catches of sweet potato whitefly, they further reported that whitefly build up increases when both temperature and relative humidity are high. This finding also agreed with the findings of Nagamandla *et al.* (2017), who stated that maximum, minimum temperature, maximum, minimum, average relative humidity, mean canopy temperature correlated significantly positive per *B. tabaci* population in open field.

Khan *et al*. (2019), also found that temperature and relative humidity had significant impact on *B. tabaci* abundance which resulted in higher population possibly due to the fact that favourable environmental condition for the survival of both immature and adult *B. tabaci*. Conversly, the results of this study contradicted the findings of Gerling *et al.* (2001), who found out that higher and lower relative humidity are unfavourable conditions to the younger stages of *B. tabaci,* this could be attributed to the possible ecological differences including climatic variations in the different regions of the world. In a related research Anjali *et al*. (2012), reveal that the effect of climatic factors on *B. tabaci* abundance was significantly correlated positively indicating a favourable relationship between them that led to the high fecundity and abundance in the study site. However, Kumari and Kumar (2017), stated that weather parameters accounted for 55.70% on *B. tabaci* population when acted together. Their findings was in agreement with the findings of this study that weather parameters such as temperature and relative humidity had significant positive correlation with *B. tabaci* population.

4.8 Conclusion

This study revealed how temperature, relative humidity and rainfall greatly influenced the abundance of *B. tabaci* in the study location in the two different seasons of 2017 and 2018 at the study site. Observing and detection of *B. tabaci* presence in the field using the Yellow Sticky Traps revealed that adult *B. tabaci* population are significantly higher in abundance in the dry seasons with peak population at the onset of the dry seasons in both 2017 and 2018 at the study location. This coincide with the period without rainfall that likely caused the build-up in the *B. tabaci* abundance on tomato plants. *B. tabaci* monitoring with indicated that relative humidity and temperature encourage and significantly increased *B. tabaci* abundance at both dry and rainy season. Rainfall was however, was observed to significantly reduced *B. tabaci* abundance in the both rainy period in both experimental years of this study. *B. tabaci* monitoring is an effective tool that provides useful insight into an efficient estimation of *B. tabaci* abundance on tomato farms for effective *B. tabaci* control strategies at appropriate time to avoid the endemic nature of *B. tabaci* in the study location.

Lastly, it could be concluded that a more profitable tomato production should be done in the dry seasons of the study area thereby increasing the economic standards of tomato farmers as a result production of higher quantity and qualitaty tomato, thus increasing the country's Gross Domestic Product.

CHAPTER 5

SEASONAL EFFECT OF DIFFERENT LIFE STAGES OF *Bemisia tabaci* ON TOMATO YIELD IN NET COVERED PLOT IN RELATION TO CLIMATIC FACTORS

5.1 Introduction

Seasonal effect is central to the ecological studies of *B. tabaci* abundance, developmental stages and its affects on tomato plant at both young and adult stages with the later been the most devastating stage, attacking both young and older plants at different seasons of the year during the experiments. The seasonal abundance determine rate of attacks on tomato plants in tmato production that determine the rate of yield losses (Awan *et al*., 2019; Time *et al*., 2020).

Whitefly abundance can change dramatically as a result of the influence of climatic factors observed to affect its abundance that was naturally subjected to the most crucial climatic variables like temperature, relative humidity and rainfall (Kumari and Kumar, 2017). According to Shivani *et al*. (2020), an increase and decrease in this climatic factors therefore determine the presence, absence, abundance and fecundity of *B. tabaci* in fields causing the most serious damages on tomato plants through feeding (De Barro and Driver 1997; Solomaon *et al.*, 2014).

Whitefly *B. tabaci* been known as among the most important pest damaging many plants (Byrne *et al.* 1990), reducing crop yield including tomato and act as vectors of viral pathogens (Kajita and Alam 1996), had lead to the spread of serious diseases (Pakkianathan and Ghanim, 2014), spreading the most destructive disease of tomato vectored by *B. tabaci* (Berlinger *et al*., 2002; Marisa and Gafini, 2010). This vector can cause significant yield losses from 90–100%, and it has been estimated that about 7 million hectares can experience TYLCV infection or mixed virus infections annually (Singh *et al*., 2011; Matete and Ndung'u, 2011). Whitefly population at the growing period of tomato plays a significant role in the spread of many viral diseases in the field and control of *B. tabaci* can be achievable significantly by planting tomato seedling in the insect-proof net house (Abu-Talha, 2007). This study is aimed to assess the seasonal effect of different life stages of B*emisia tabaci* on tomato yield in net house in relation to climatic factors

5.2 Materials and Method

This study was conducted in the insect net covered plots which is a structure enclosed by an Agronets woven material that do not allow other stray insects to get access into the net but allow the required sunlight, moisture and air to pass through the gaps (Behera *et al*., 2016). This allows for evaluation of only the effects of *B. tabaci* on tomato by preventing entry of non desired insect into the net covered plots. The maximum temperature is 41ºC and the minimum is 15 ºC in the study location.

5.2.1 Experimental Plots

The experiment was conducted in four insect net covered with plots, replicated three times in a RCBD design using a net material (Bio Quip Products) of an area of 0.99 m x 1.2 m and 1.2 m height made up of a screen net mesh of 0.02 x 0.08 mm of hole sizes from knitted polymide (Taggar *et al*., 2013). The net is held by means of four wooden stands (pushed about 30 cm deep in the soil at the base) from each angle used as the net house. Four plots covered with the insect proof nets were replicated three times arranged in Randomised Complete Block Design. This gave a total of 12 plots of four rows with each having 10 stands covered plots having 20 tomato stands per each plot totalling 120 tomato plants for the experiments. Tomato variety Roma VFN was used as the test crop.

5.2.2 Insect Culture

Adult *B. tabaci* were collected from infested tomato plants in the fields of the Kebbi State University Farm, Jega. The adult *B. tabaci* collected were reared in a rectangular cage (37x28cmx22cm in size) covered by a fine mesh under ambient temperature, light and humidity, cultured on tomato plants to oviposit and hatch into nymphs and to fresh one week old adult stages one month before the experiment commenced. *B. tabaci* were reared on tomato plants in a cage measuring 0.5 x 1.20 m and 1.20 m at the bottom, one month before starting the experiment. About 100 newly emerged one-week-old *B. tabaci* were introduced using the Pocket Pooter Aspirator into each separate insect-proof plots having four weeks old growing tomato plants (Toscano *et al*., 2002).

5.3 Data Collection

5.3.1 Data Collection on *B. tabaci* Abundance on Tomato Plants

Count on *B. tabaci* abundance was performed by the direct count method adopted from Naranjo and Flint (1995), counting the number of *B. tabaci*, seen on the 5 randomly selected and tagged plants from each plot at weekly intervals, commencing from three weeks after transplanting. This commences from two weeks after transplanting and lasted for twelve weeks in both dry and rainy seasons of 2017 and 2018 and recorded per plot. Sampling was carefully performed by examining each selected plant early in the morning (between 6:00 to 8:00 am) when *B. tabaci* were particularly less active and much easier to spot and count. Counting all the *B. tabaci* adults, nymphs and eggs found with the aid of a Hand Lens and recorded on a data sheet. These 5 randomly selected plants were tagged from each net house for data collection, sampling the adults, nymphs and eggs was performed only on the 6 selected leaves from each tagged plants, by carefully turning over the undersides of leaves of tomato plants to count the *B. tabaci* adults, nymphs and eggs present. Leaf samples for egg counts from the sampled leaves were then counted in the laboratory under a Dissecting Microscope. The climatic factors recorded during this study were mean weekly temperature, average weekly relative humidity with the exception of rainfall parameter which was not used in the net house experiment as the tomato plants are enclosed in the net house which disrupts the normal inflow of rainfall into the insect net enclosed house.

5.3.1.1 Number of Flowers Produced Per Plant

Number of flowers produced per plant were obtained by randomly selecting and tagging 5 tomato plants in each plot and recorded, this was performed when about 50% of the tomato plants in the net house were assumed to produce flowers at week 9, 10, 11 and 12.

5.3.1.2 Number of Fruits Per Plant

Number of fruits per plant was taken from the weekly observation on fruits produced on the 5 tagged plants from each plot counting the number of fruits produced by each plant, commencing from 50% fruit formation to final harvest at week 9, 10, 11 and 12.

5.3.1.3 Number of Irregular Fruit Per Plant

Irregular ripening is characterized by the partially ripened, delayed ripening and a change in the shape of fruits in each plot and recorded monthly at week 10, 11, 12 and 13. Number of irregular fruit per plant was obtained by counting all uneven ripened fruits on the 5 randomly sampled and tagged plants in each plot commencing from fruit ripening stage to final harvest.

5.3.1.4 Number of Dead Plant Per Plot

Number of dead plant per plot was by visually obtained observing and counting the total number of dead (collapsed plant with permanent wilted/dry leaves, decaying stems and roots) plants in each plot and recorded which commencing at weeks 5, 8, 10 and 12 after transplanting at time intervals to harvest. Plants were considered dead when all the leaves turned brown and dried.

5.3.1.5 Tomato Fruit Yield Per Plant

Tomato Fruit Yield was obtained by harvesting and weighing all the tomato fruits produced in by the tagged plants in each plot, the cumulative total fruit harvested from week 8, including the marketable and non-marketable ones, were all weighed per plot (Degri and Sani, 2015; Kenneth *et al*., 2016).

5.4 Data Analysis

The averaged data on mean weekly number of whitefly adults, nymphs and eggs were taken from 5 randomly selected and tagged tomato plants from each covered plots and subjected to the Analysis of Variance and the Pearson's Correlation analysis using SAS version 9.4 (SAS Institute Inc. 2014).

5.5 Results

5.5.1 *B. tabaci* Adult Abundance on Tomato in the Covered Net as Affected by Season

B. tabaci adult abundance monitored inside the insect proof net was significantly ($P<0.05$) correlated (Pearson correlation r, at $p<0.05$) positively with the mean weekly temperature, humidity and rainfall on tomato in both dry and rainy seasons of 2017 and 2018. Mean temperature ($r=0.927$) and relative humidity ($r=0.723$) significantly ($P<0.05$) favoured higher *B. tabaci* adult abundance in the dry period of 2017. Similarly, a positive correlations resulted with temperature ($r=0.591$) with the least strength of relationship which resulted between the relative humidity and *B. tabaci* abundance ($r=0.449$) in the dry season of 2017 as shown in Table 5.1. This result obtained may likely be due the higher temperature regimes prevalent in the study area where temperature is always suitable for *B. tabaci* survival, growth and development. This indicated the relevance and significance of the climatic factors in the development *B. tabaci* population on tomato. This led to the higher abundance of *B. tabaci* adults in both 2017 and 2018 dry seasons revealing that temperature ($r=0.591$) and relative humidity ($r=0.530$) correlated significantly ($P<0.05$) positive with the adult abundance (Table 5.1).

Table 5.1 : *B. tabaci* Adult Abundance on Tomato in the Net House as Affected by Season

Year	Season	Abiotic factors	R^2	Coefficient of Correlation (r)
	Dry	Temperature	0.8610	0.927*
2017		R. Humidity	0.5232	0.723*
	Rainy	Temperature	0.3471	0.591
		R. Humidity	0.2013	0.449
	Dry	Temperature	0.3489	0.591
2018		R. Humidity	0.2810	0.530
	Rainy	Temperature	0.7113	0.849*
		R. Humidity	0.4485	0.670*

* Significant at P<0.05

5.5.2 *B. tabaci* Nymph Abundance on Tomato in the Covered Net as Affected by Season

Results on the nymphal abundance revealed that temperature had the strongest positive relationships with the *B. tabaci* nymph abundance (0.927) in the dry season of 2017 followed by the relative humidity (0.742) in the same dry season of 2017. Similarly, temperature favourably correlated with the nymphal abundance in the dry and rainy seasons of 2018 while the relative humidity had weaker relationship with the abundance of nymphs (Table 5.2).

Table 5.2 : *B. tabaci* Nymph Abundance on Tomato in the Net House as Affected by Season

Year	Season	Abiotic factors	R^2	Coefficient of Correlation (r)
	Dry	Temperature	0.8900	0.927*
2017		R. Humidity	0.8589	0.742*
	Rainy	Temperature	0.1631	0.404
		R. Humidity	0.1122	0.335
	Dry	Temperature	0.3322	0.576*
2018		R. Humidity	0.2113	0.460
	Rainy	Temperature	0.3002	0.550*
		R. Humidity	0.1210	0.348

* Significant at P<0.05

5.5.3 *Bemisia tabaci* Egg Abundance on Tomato in the Net House as Affected by Season

The egg abundance of *B. tabaci* on tomato correlated with both temperature and relative humidity in 2017 and 2018. Egg abundance had a significant positive correlation with the temperature (r=0.592) and had a weak positive relationship with the relative humidity (r=0.447) in the dry season of 2017. Egg abundance also correlated significantly positive with temperature (r=0.608) and relative humidity (r = 0.560) in the dry season of 2018 but recorded a non-significant (P<0.05) positive correlation with temperature (r=0.398) and relative humidity (r=0.363) in the rainy season of 2018. These climatic factors determine the adult abundance thus directly correlating with the number of eggs laid by the *B. tabaci* during this study as depicted in Table 5.3.

Table 5.3 : *B. tabaci* Egg Abundance on Tomato in the Net House as Affected by Season

Year	Season	Abiotic factors	R^2	Coefficient of Correlation (r)
2017	Dry	Temperature	0.351	0.592*
		R. Humidity	0.200	0.447
	Rainy	Temperature	0.310	0.557*
		R. Humidity	0.200	0.448
2018	Dry	Temperature	0.369	0.608*
		R. Humidity	0.313	0.560*
	Rainy	Temperature	0.156	0.398
		R. Humidity	0.132	0.363

* Significant at P< 0.05

5.5.4 *B. tabaci* Effects on the Tomato Performance in Dry and Rainy Seasons of 2017 in the Study Area

Results from Analysis of Variance (ANOVA) indicated that the mean number of flower damage per plant in both dry (32.5±0.18) and rainy (29.1±0.16) seasons significantly (P<0.05) differed indicating more flower damages in the dry seasons than in the rainy seasos due to the highest abundance of *B. tabaci* recorede n the dry seasons of 2017. However, results on fruit production per plant were significantly higher (P<0.05) in the dry season of 2017 (7.52±0.11) to that of the rainy season (11.09±0.14) of the same year, but revealed a non-significant difference on the number of irregularly ripened tomato fruits in the dry season (15.02±0.12) and that of the rainy season (14.80±0.10). Fruit yield per plot were significantly (P<0.05) higher in the dry season (8.51±0.18) than that of the rainy season (4.09±0.13). Similar trend was obtained on the number of dead plants per plot where the the number tomato plant mortality in the dry season (11.80±0.15) was significantly higher (P<0.05) than that of the rainy season (7.30±0.16) of 2017 as depicted in Table 5.4.

Table 5.4 : Tomato Performance as Affected by *B. tabaci* Infestation in the Dry and Rainy Season of of 2017

Season	No. of Flower damage/plant	No. of Fruit per Plant	No. of Irregular Fruits /plot	No. of Fruit Yield/Plot (Kg)	Number of dead plants/plot
Dry	32.50±0.18a	7.52±0.11b	15.02±0.12a	8.51±0.18a	11.80±0.15a
Rainy	29.10±0.16b	11.09±0.14a	14.80±0.10a	4.09±0.13b	7.30±0.16b
LSD	3.20	1.33	1.12	1.96	1.53

Means with a similar letter within the same column are not significantly different at P=0.05 level of probability.

5.5.5 Mean Weekly *B. tabaci* Abundance on Tomato Performance in Dry and Rainy Seasons of 2018 in the Study Area

Significantly higher flower damage was recorded in the dry season (38.70±0.12) than of the rainy season (27.40±0.11) in 2018. Fruit production per plant was significantly higher in the rainy (10.92±0.15) season tha the dry season of 2018 as shown in Table 5.5. Similarly, irregularly ripened tomato fruits differed significantly between the dry (17.13±0.14) and rainy (11.93±0.16) seasons depicting more irregular tomato fruits in the dry season than in the rainy season. Significantly ($P<0.05$) higher fruit yield was obtained in the dry season than in the rainy season of 2018. Result showed a non-significant different on the number of dead tomato plants in both the dry (8.70±0.19) and rainy (9.10±0.13) seasons of 2018 as shown in Table 5.5.

Table 5.5 : Tomato Performance as Affected by *B. tabaci* Infestation in of 2018

Season	No. of Flower damage/plant	No. of Fruit per Plant	No. of Irregular Fruits⁄plot	Fruit Yield/Plant (Kg)	Number of dead plants/plot
Dry	38.70±0.12a	6.06±0.13b	17.13±0.14a	4.87±0.19a	8.70±0.10a
Rainy	27.40±0.11b	10.92±0.15a	11.93±0.16b	3.10±0.10b	9.10±0.13a
$LSD_{0.05}$	3.12	1.90	1.40	1.81	1.43

*Means with a similar letter within the same column are not significantly different at P= 0.05 level of probability.

Linear regression results also depicted similar results to those obtained in the correlation analysis on the abundance of the six insect pests monitored in relation to the three climatic factors in this study. The decription of the relationships produced response variables; $Y= 0.478x+19.658$; $R^2=0.748$ for *B. tabaci* adult abundance in relation to the temperature in the dry seasons of 2017 and 2018. With a similar outcome in the rainy season $Y=2.267x+20.255$; $R^2=0.842$, producing various levels of relationships with the relative humididty and rainfall as shown in Appendices D11-D22.

5.6 Discussion

Results obtained in the insect proof net study on *B. tabaci* abundance and effect on tomato during the 2017 and 2018 showed higher abundance of *B. tabaci* was favoured by the mean weekly temperature and relative humidity correlated significantly positive that led to higher abundance and caused significant damages on tomato plants.

This was because temperature and humidity in the study location provided conducive for the growth and development of *B. tabaci* leading to the upsurge in abundance during this study. This result is also in agreement with the findings of Brown and Idris (2005)and Chang *et al.,* (2008), who reported that temperature accounted for 75 to 85% *B. tabaci* population variability and the relative humidity explained 78 to 85% contribution on tomato plants. Rainfall however did not favour *B. tabaci* abundance as it had significantly negative relationship with both *B. tabaci* adults, nymphs and eggs in all the plots covered with nets. This may be attributed to the destruction of *B. tabaci* eggs, nymphs and adults by heavy rains. This study disagreed with the study conducted by Kaur *et al.* (2010); Khalid and Muhammad (2014), who found out that the number of total rainfall and rainy days was negatively correlated with *B. tabaci* abundance. Resulting in more abundance in the dry season when rainfall was completely absent, thus giving rise to conducive situation for its growth and development leading to higher abundance. This is supported by the works of Degiri and Sani (2015), that tomato production in the tropics such as Nigeria is constrained by a complex of insects with *B. tabaci* been the most damaging insect pest in the dry seasons.

The abundance of *B. tabaci* affected tomato yield by suppressing both flower and fruit production (Thriveni, 2019), and caused higher tomato mortality in both years, which could likely be attributed to the direct and indirect detrimental effects of *B. tabaci* infestation by vectoring many viral diseases and secretion of honey dew on tomato plant (Shivani *et al.,* 2020). Infestation leads to tomato yield reduction that led to fall in fruit production due to infestation. Previous findings supported this study as *Bemisia. tabaci* is ranked among the most serious threat on tomato production that transmits diseases on tomato through systemic and physical effects caused by both adult and nymphal feeding were attributed to be main cause of lower yields and irregular ripening of tomato fruits (Alam *et al.*, 2016; Muhammad *et al*, 2017: Vijaya *et al*., 2020).

This study indicate the level of damages caused by *B. tabaci* as a result of infestation on tomato where the number of flower per plant, fruits per plant, fruit per plot were significantly reduced as a results of the higher *B. tabaci* while significantly increasing the number of irregularly ripened fruits and number of dead tomato per plant in the dry season than the in the rainy season. This is likely as a result of more *B. tabaci* abundance synergized by the climatic factors that led to higher infestation, thus, negatively affecting the performance of tomato plants during the study period. This is also in tandem with the results of Mutisya *et al.* (2016), who stated that *B. tabaci* is one of the major pests of tomato, potentially causing up to 100% yield loss. Infestation leads to tomato yield reduction as reported by Degri and Sani (2015), tomato fruit infestation by *B. tabaci* revealed a significantly lower plant height, few branches and few number of fruits per plant. According to Kumari and Kumar (2017), weather parameters were found to contribute 55.70 per cent impact on the *B. tabaci* population on tomato plant, which agrees with the results obtained in this study in which temperature and humidity played significant roles in the growth and development of this insect pest affecting tomato production in the study site in both seasons. Relative humidity and temperature are the main climatic factors that mainly influenced *B. tabaci* activity with temperature been the most crucial abiotic factor in this regards (Khan and Hossain, 2018). On the nature of *B. tabaci* damage on tomato Matilda *et al*. (2012), Zenshwan *et al*. (2015) and Thriveni (2019), found that *B. tabaci* causes significant damage to plants like tomato by feeding on the phloem, transmitting different viral infections, excretion of honeydew including phytotoxic disorders.

However, similar research research did not agree with the findings of Khalid *et al*. (2014) and Sanjeeb *et al*. (2019), who stated that temperature and humidity showed negative correlation with *B. tabaci* population. The variation may likely resulted due to the difference in climatic between the different regions the researches were conducted. Similarly, Shivani, (2020), reported a negative relationship between temperature and relative humidity with *B. tabaci* population revealing that temperature accounted for -48% reduction and humidity produced 51% reduction in *B. tabaci* population. In a related work by Sharma *et al*. (2017), the outcome of their research revealed that the correlation studies between *B. tabaci* population and temperature (both minimum and maximum) showed significant positive correlation and a negative but non-significant negative with relative humidity (both minimum and maximum), and a positive but non-significant correlation was observed with rainfall. This is further supported by the work of Time *et al*. (2020), who found that 27%, 42% and 57% of *B. tabaci* population could be explained by temperature, humidity and wind speed respectively which corroborate with the present study on temperature and humidity.

5.7 Conclusion

Whitefly, *B. tabaci* infestation affected both the growth and development of tomato that led to the reduction in quantity and quality of fruits produced in both seasons of 2017 and 2018, this resulted in the reduction of the total number of tomato fruits and the market quality of tomato fruits produced. Furthermore, led to a reduction in tomato plant population because of upsurge of plant mortality likely due to the diseases vectored by *B. tabaci* on tomato. It could be concluded that temperature, relative humidity and rainfall were found to play significant roles in the dictating of *B. tabaci* population on tomato plants. Whitefly adults and nymphal population on tomato recorded higher abundance during the dry seasons, indicating potentially higher whitefly infestation during the dry periods in the study location during this study. Positive and significant correlation on a weekly number of whitefly with the average weekly relative humidity showed that increase in relative humidity further indicates increased in the number of whitefly adults and nymph population on tomato. The higher the *B. tabaci* abundance the higher the infestation and damages on tomato flower, fruits and overall yields depicting the detrimental effects of *B. tabaci* on tomato production in the study location. These climatic factors therefore, are good determinants of abundance of *B. tabaci* abundance in the study location at a given time, thereby, assisting farmers and crop protectionists in understanding the pattern and behaviour of the insect pests of crops in designing effect planning and control of *B. tabaci* on crops like tomato.

CHAPTER 6

SEASONAL INFESTATION OF DIFFERENT LIFE STAGES OF *Bemisia tabaci* ON TOMATO YIELD IN THE FIELD IN RELATION TO CLIMATIC FACTORS

6.1 Introduction

Results from chapter 4 confirmed the significant role of environmental of temperature, relative humidity and rainfall along with seasonal changes affecting the abundance of *B. tabaci* and intensity of infestation on tomato plant growth and yields in the the experimental plots. However, detailed studies on the exact ecological relationships between this insect in the study location is still lacking especially its actual time of abundance were not known prior to this research in the study location. Damage caused by *B. tabaci* to tomato were observed to be directly through phloem feeding by *B. tabaci*, or indirectly by its transmission of plant viruses as a vector (Bikash *et al*., 2017). The pest had becomes prevalent in the research area which is a hot climatic tropics and spreading continuously, reported in many areas that it was not found before (Moshe *et al.*, 2014). Abundance of *B. tabaci* gradually increased with environmental temperature and humidity to a certain tomato growth stage and decrease as the crop ages, at high temperature and low relative humidity *B. tabaci* infestation was at its maximum causing more damages on tomato (Latif and Akhter, 2013).

Visual observations of *Bemisia tabaci* on tomato plants in an open field were observed to provide the most accurate information and a practical method for assessing and estimating whitefly population levels by sampling involving counting the number of leaves with one or more whitefly, that are present or absent (Palumbo *et al*., 2001). The actual number of *B. tabaci* on a leaf is unimportant, these numbers are related to the mean number of *B. tabaci* per leaf across the field (Toscano *et al*., 2002). The insect is a serious pest of tomato throughout the study periods, with adults transmitting viral diseases on a tomato plant, capable of causing severe losses even at low densities let alone at peak populations in the dry season and early rains (Mahmood *et al*., 2002). Both juvenile and adult *B. tabaci* were observed to be feeding on the phloem of the leaves by inserting a sucker mouth part into the leaf, thereby transmitting the virus to the plant through the saliva from the mouth injected into the plant while *B. tabaci* feed, disturbing plant growth and ultimately reducing yield, seedlings are particularly affected. Feeding by the immature whitefly, causing plant distortion, dis-colouration, or silvering of leaves, and may lead to serious losses in tomato crops in the experimental farm.

The damages are of different types and substantially on *B. tabaci* causing detrimental indirect destruction on tomato including the honeydew released by every developmental stages of *B. tabaci*, principally the late nymphal instars when the environmental factors are most favourable (Mansour *et al*., 2012). The accumulation of this honeydew on the leaves or on fruit surfaces encourages the growth of sooty moulds, which affect yield both in quantitative and qualitative terms (Basu. 1995; Devinder *et al*., 2017; Sameena *et al*., 2019). The nymphs secrete honeydew (sugary sap) that serves as a growing medium for the black sooty mould fungi which reduces photosynthesis and on severe infestations leaf defoliation occurs in tomato plants if the climatic factors are condusive (Devinder *et al*., 2020). Therefore, this study was undertaken with the objective to determine the seasonal infestation of *B. tabaci* growth stages on tomato yield in the field in relation to climatic factors.

6.2 Materials and Methods

Two field studies were conducted in the Kebbi State University of Science and Technology, Teaching and Research farm in Jega Town (Latitude 12^{o} 11$^{'}$ N; Longitude 4^{0} 16$^{'}$ E), during the 2017 and 2018 dry and rainy seasons with one planting cycle per each season lasting for 12 weeks in each season. The area lies within the Sudan Savannah Agro-ecological zone of Nigeria, characterized by erratic and scanty rainfall that lasts for about 6 months (May to October) and long dry period (October to April) (Eberibe *et al.*, 2017). The weather been a semi-arid with a mean rainfall of about 550-650mm per year. The relative humidity ranges from 21-47% and 51-79% during the dry and rainy seasons, respectively. *Temperature* averages between 14-43 ^{0}C during the dry season and 27-41 ^{0}C during the rainy season (Eberibe *et al.*, 2017). Roma VFN tomato variety was planted and replicated four times in four plot sizes of 3m x 4m (12 m^{2}) using the Randomized Complete Block Design (RCBD). Certified tomato were acquired at Kebbi State Agricultural Company, Birnin-Kebbi. Nursery beds were prepared for the seedlings which were transplanted 30-35 days after planting. Abiotic factors recorded weres Temperature, Relative Humidity and Rainfall as obtained from the Meteorological Station of the Faculty of Agriculture, Kebbi State University, Nigeria.

6.3 Data Collection

6.3.1 *B. tabaci* adults, Nymphs and Egg Sampling

This was performed by counting all the individual numbers of *B. tabaci* adults, nymphs and eggs seen on 10 randomly selected and tagged tomato plants from each subplot at weekly intervals for 12 weeks using a Hand Lens in the field (Adopted from Fargette *et al*., 1996). Sampling commenced at 2 weeks after transplanting.

6.3.2 Number of Flowers Produced Per Plant

Number of flowers produced per plant were achieved through randomly selecting and tagging 10 stands per plot and recorded, this was performed when about 50% of the stands assumed to produce flowers at week 9, 10, 11 and 12.

6.3.3 Number of Fruits Per Plant

This was obtained by weekly observation on fruits produced on the 5 tagged plants from each plot counting tomato fruit numbers produced by each plant, commencing from 50% fruit formation to final harvest at week 9, 10, 11 and 12.

6.3.4 Number of Irregular Fruit Per Plant

Was performed by counting all uneven ripened fruits on sampled plants in each plot commencing from the fruit ripening stage to final harvest. Irregular ripening has been characterized by partially ripened parts of fruit in each plot and recorded monthly at week 10, 11, 12 and 13.

6.3.5 Tomato Fruit Yield Plant

Tomato Fruit Yield was obtained by harvesting and weighing all the tomato fruits produced in by the tagged plants in each plot, the cumulative total fruit harvested from week 8, including the marketable and non-marketable ones, were all weighed per plot (Li *et al*., 2022).

6.3.6 Number of Dead Tomato Plant Per Plot

Number of dead plant per plot was by visually obtained observing and counting the total number of dead (dry) plants in each plot and recorded which commenced at weeks 5, 8, 10 and 12 after transplanting at intervals to harvest. Plants were considered dead when all the leaves turned brown and dried.

6.4 Data Analysis

Data obtained were subjected to a one way ANOVA and Pearson's correlation analysis using SAS (SAS, 2014). Means found to be significant were separated using the Least Significant Difference (LSD) at 0.5%.

6.5 Results

6.5.1 Relationship of Climatic Factors with *B. tabaci* Adult Seasonal Abundance

Results on *B. tabaci* abundance in relation to temperature and the relative humidity revealed that higher adult abundance resulted in both the dry and rainy seasons of both years, but rainfall was found to significantly ($P>0.05$) reduced *B. tabaci* adults in the rainy seasons of both 2017 and 2018, this may be attributed to the impact of heavy rainstorms during the rains. Results revealed *B. tabaci* adult abundance was influenced by the prevailing climatic conditions in both dry and rainy seasons of 2017 and 2018 during the study period as temperature and humiditysignificantly ($P>0.05$) encouraged more number of adults as revealed in this study that had correlated significantly ($P<0.05$) positive with temperature ($r=0.639$) and the relative humidity ($r=0.570$) in the dry season of 2017. Similar results on temperature ($r=0.823$) and relative humidity (r=0.534) in the rainy season of 2017 while rainfall (r=-0.975) had significantly correlated negatively with the adult abundance in 2017 as depicted in Table 6.1. Similarly, in dry season of 2018, temperature (r=0.644) and relative humidity (r=0.568) significantly correlated positively with the adult abundance, with a repeating trend in the rainy seasons where temperature (r=0.821) and relative humidity (r=0.634) had significant positive correlation. However, rainfall also had a significant negative relationship with the adult abundance (r=-0.982) in 2018 depicting higher *B. tabaci* adult abundance in the dry seasons than the adult abundance in the rainy seasos of both 2017 and 2018 as shown in Table 6.1.

Table 6.1 : Relationship of Climatic Factors with *B. tabaci* Adult Seasonal Abundance

Year	Season	Abiotic factors	R^2	Coefficient of Correlation (r)
2017	Dry	Temperature	0.4311	0.639*
		R. Humidity	0.3441	0.570*
	Rainy	Temperature	0.6740	0.823*
		R. Humidity	0.5355	0.534*
		Rainfall	0.9730	-0.975*
2018	Dry	Temperature	0. 4419	0.644*
		R. Humidity	0.3100	0.568*
	Rainy	Temperature	0.6740	0.821*
		R. Humidity	0. 3991	0.634*
		Rainfall	0.9730	-0.982*

* Significant at P<0.05

6.5.2 Relationship of Climatic Factors with *B. tabaci* Nymph Seasonal Abundance

Results on the abundance of *B. tabaci* nymphs in the dry season in this study revealed the dry season temperature (r=0.830) had significantly increased nymph abundance as well as the relative humidity (r=0.759) during the dry season of 2017 which had significant positive correlation with the with *B. tabaci* nymph abundance on tomato in the field trial. This may likely be due to the conducive environmental temperature and relative humidity that existed in the dry seasons for *B. tabaci* nymphal survival and growth. In the rainy season of 2017. Similar resultsas obtained in the rainy season of 2017 which revealed that nymph abundance had correlated significantly positive with the climatic factors, temperature (r=0.710) and the relative humidity (r=0.644).

While rainfall (r=-0.673) drastically reduced nymph abundance that negatively correlated significantly with the rainy season *B. tabaci* nymph abundance in 2017 (Table 6.2). Temperature (r=0.629), relative humidity (r=0.537) in the dry season of 2018 was negatively correlated and further had significant correlation with temperature (r=0.722) and relative humidity (r=0.618) in the rainy season of 2018. While rainfall (r=-0.737) was significantly correlated negatively with the nymph abundance, resulted in significant reduction of the nymphs in the rainy season leading to fewer nymphal abundance in both the rainy seasos of 2017 and 2018 as revealed in Table 6.2.

Table 6.2 : Relationship of Climatic Factors with *B. tabaci* Nymph Seasonal Abundance

Year	Season	Abiotic factors	R^2	Coefficient of Correlation (r)
2017	Dry	Temperature	0.6891	0.830*
		R. Humidity	0.5754	0.759*
	Rainy	Temperature	0.5036	0.710*
		R. Humidity	0.4150	0.644*
		Rainfall	0.4593	-0.673*
2018	Dry	Temperature	0.3955	0.629*
		R. Humidity	0.2891	0.537*
	Rainy	Temperature	0.5218	0.722*
		R. Humidity	0.3808	0.618*
		Rainfall	0.4439	-0.737*

* Significant at P<0.05

6.5.3 Relationship of Climatic Factors with *B. tabaci* Seasonal Eggs Abundance

The results on *B. tabaci* egg abundance revealed significant positive relationship with the mean weekly temperature (0.567) and relative humidity (0.459) in the dry season of 2017. The more the increase in temperature the more the number of eggs recorded on tomato in this study. But had weak positive association with the relative humidity (0.358) and significantly reduced egg abundance by the rainfall (-0.558), depicting a significant negative interraction in the 2017 rainy season (Table 6.3). However, in the rainy season of 2018, moderate egg abundance was recorded as weaker relationship resulted between the egg abundance and the climatic factors. Showing egg abundance having weaker positive relationships with the temperature (0.433) and the relative humidity (0.446) during the rainy season and had moderately non-significant negative relationship with rainfall (-0.485), thereby drastically reducing *B. tabaci* egg abundance in the rainy seasos of both 2017 and 2018 depicting an adverse interraction as revealed in Table 6.3.

Table 6.3 : Relationship of Climatic Factors with *B. tabaci* Eggs Seasonal Abundance

Year	Season	Abiotic factors	R^2	Coefficient of Correlation (r)
2017	Dry	Temperature	0.3213	0.567*
		R. Humidity	0.2105	0.459
	Rainy	Temperature	0.3561	0.597*
		R. Humidity	0.1282	0.358
		Rainfall	0.3110	-0.558*
2018	Dry	Temperature	0. 2125	0.461
		R. Humidity	0.2009	0.448
	Rainy	Temperature	0.1878	0.433
		R. Humidity	0.1987	0.446
		Rainfall	0.2352	-0.485

* Significant at P<0.05

The same data when subjected to the regression analysis yielded the same results with the ones obtained in the correlation analisis as depicted in Appendices D23 - D35.

6.5.4 Tomato Performance as Affected by *B. tabaci* Infestation in the Field in the Dry and Rainy Seasons of 2017

Results revealed *B. tabaci* infestation significantly (P<0.05) affected tomato performance and yield in the dry season of 2017, with significantly higher damages recorded in the dry season. Significantly (P<0.05) higher flower damage per plant was recorded in the dry season (56.3±2.82) than that of the rainy season flower damage (47.2±1.34) depicting the highest *B. tabaci* infestation in the dry season as revealed in Table 6.4. Higher fruit production per plant was recorded in the rainy season (21.3±1.87) of 2017 than in the dry season (10.9±1.05). Similarly, results on fruit per plant revealed a detrimental effect of *B. tabaci* infestation on tomato fruit production with higher fruit production in the rainy season of 2017. The number of irregular fruit per plant obtained was also significantly higher (P<0.05) in the dry season (34.8±2.08) than the number of irregular fruit produce per plant in the rainy season (23.4±1.91), confirming the negative effect of infestation by *B. tabaci* on tomato. Fruit yield per plant was however, significantly higher in the rainy season (14.8±2.03) than the dry season fruit yield per plant (9.12±1.01), likely due to higher *B. tabaci* abundance in the dry season thereby causing higher infestation on tomato which reduced tomato fruit yield. Higher infestation by *B. tabaci* in the dry season also led to significantly higher (P<0.05) tomato plant mortality recorded on the number of dead tomato plants per plot obtained in the dry season (31.8±1.14) than that obtained in the rainy season (23.4±1.91) of 2017, further revealing the negative effects of *B. tabaci* infestation on tomato growth and yield in the dry season when *B. tabaci* was higher in abundance resulting to significantly higher damages in the study area in 2017 as shown in Table 6.4.

Table 6.4 : Tomato Performance as Affected by *B. tabaci* Infestation in the Field in 2017

Season	No. of Flower damage/plant	No. of Fruit per Plant	No. of Irregular Fruits⁄plot	Fruit Yield/Plant (Kg)	Number of dead plants/plot
Dry	56.3±2.82a	10.9±1.05b	34.8±2.08a	9.12±1.01b	31.82. ±1.14a
Rainy	47.2±1.34b	21.3±1.87a	23.4±1.91b	14.8±2.03a	23.4±1.91b
$LSD_{0.05}$	3.56	2.80	3.51	2.52	3.76

*Means with a similar letter within the same column are not significantly different at P = 0.05 level of probability.

6.5.5 Tomato Performance as Affected by *B. tabaci* Infestation in the Dry and Rainy Seasons of 2018

Significantly higher (P<0.05) flower damage was recorded in the dry season (41.9±1.12) of 2018 probably due to higher abundance of *B. tabaci* during the dry season than in rainy season, singnificantly higher than the flower damage recorded in the rainy season (36.7±2.09) and was significantly higher in the flower damage recorded in 2018. Infestation by the whitefly resulted in significant reduction in fruit production in the dry season (12.1±2.06) than the rainy season (18.2±1.93) fruits produced per plant indicating the detrimental effect of high *B tabaci* adult abundance in reducing tomato fruit yield in the dry season which resulted in more fruit production in the rainy season of 2018. Results revealed significantly (P<0.05) higher tomato fruit damage was recorded in the dry season (30.3±2.01) where more irregularly ripened tomato fruits per plot were obtained with the rainy season (23.6±1.50) been significantly lower in terms of irregularly ripened fruit production. Significantly higher fruit yield per plant was recorded in the rainy season (18.2±1.32), more than the dry season (10.6±1.66) yield which may likely be atributed to the higher infestation by *B. tabaci* in the dry season. Significantly higher tomato plant mortality was recorded in the dry season (21.2±1.87) compared to that obtained in the rainy season (11.6±1.61) as depicted in Table 6.5.

Table 6.5 : Tomato Performance as Affected by *B. tabaci* Infestation in the Field in 2018

Season	No. of Flower damage/plant	No. of Fruit per Plant	No. of Irregular Fruits/plot	Fruit Yield/Plant (Kg)	Number of dead plants/plot
Dry	41.9±1.12a	12.1±2.06b	30.3±2.01a	10.6±1.66b	21.2±1.87a
Rainy	36.7±2.09b	18.8±1.93a	23.6±1.50b	18.2±1.32a	11.6±1.61b
$LSD_{0.05}$	3.98	2.80	3.87	1.50	2.97

*Means with a similar letter within the same column are not significantly different at P= 0.05 level of probability.

6.6 Discussion

Results on the relationship of climatic factors with adult *B. tabaci* abundance in this study is in agreement with a related work by researchers such as McCollum *et al.* (2012), reported that a significant negative correlation existed between whitefly adults and nymphs and temperature, but significantly positive correlation obtained with mean relative humidity. Result obtained on relative humidity is supported by the findings of Sharma *et al.* (2017), who stated that low humidity is the major mortality factor on whitefly in Israel, leading to cessation of oviposition and resulting to high adult mortality. This result also agreed with the result of Khuram *et al.* (2012), that whitefly population is significantly and positively correlated with temperature and relative humidity but negatively with rainfall. Brown and Idris (2005), stated that humidity (maximum and minimum) and rainfall showed a negative correlation with whitefly population in the field. Similarly, Solomon *et al.* (2014), found that whitefly population increased in September and October and correlated with higher relative humidity (80-90%) and increasing temperature (36-38º C) as these favouring the development of the immature stages of *B. tabaci* by shortening the period of each stage, this agrees with this study. The inverse relationship between whitefly populations with rainfall in the rainy season could be attributed to the un-favourably lower humidity rates and the physical beating effects of rainfall that kills the insect pest in the rainy season.

Findings from this study corroborates with the findings of Mohd. *et al*. (2009), who reported that whitefly population start increasing and reached the highest peak during the flowering and fruiting stages, as a result of increased availability of food particularly with increasing trend of temperature that increased the activity of whitefly and increased infestation during its growth stages in dry seasons indicating that temperature had correlated significantly with nymph abundance was also confirmed in related findings by Rote and Puri (1991), who also reported that mean temperature had significant positive influence on *B. tabaci* nymphal population. This result is further supported by Leite *et al*. (2006), found out that the density of whitefly adults prefer apical leaves due to better nutritional quality of smaller and younger leaves as the adults lay more eggs during and after feeding at the upper canopy. This findings also agrees with the findings of Cavalho and Olievera (2019) who reported that whitefly adult population showed significant positive correlation with relative humidity and sunshine hours, while Sunshine hours also showed significant positive correlation with the nymphal population. Naranjo & Flint (1995) found that adults were consistently more abundant on main stem leaves from the top stratum of cotton plants than on the main stem leaves from the middle and lower strata. This tallied with result of present study, but contradicted the findings of Khan and Hossain (2018) who found that nymph and pupal population were highest on the middle leaves than on the upper parts of leaves. Rao and Puri (1991), also reported that significantly higher nymph numbers (98.3%) was found on tomato leaves. However, Khalid *et al*. (2006), in their study found that the adult whitefly preferred the leaves at the upper stratum than at the middle and lower strata.

Result obtained from this study on the relationship between whitefly population and rainfall strongly agreed with the findings of Ohnesorge *et al*. (1981), who stated that the oviposition by whitefly was impaired by rain as it led to a drastic reduction of its population. In contrast to this result, Umar *et al.* (2003), reported a negative correlation between whitefly population and weather factors i.e., temperature, relative humidity and precipitation. This could be likely due to the differences in the climatic factors between the location of this study with similar researches conducted other regions of the world. This result also contradicts the result of Taggar *et al.* (2003) and Khuram *et al*. (2013), that whitefly population is significantly and positively correlated with temperature and relative humidity but negatively with rainfall. Temperature adversely affected the egg abundance on the upper, middle and lower canopies by revealing a highly significant negative correlation as depicted in Table 6.4.

The present study also revealed significant correlations with both temperature and relative humidity with the egg abundane as a result of having more number o adult *B. tabaci* that layed more eggs as a result of increase in fecundity due to this favourable conditions, this result is supported by Naranjo & Flint (1995), Khalid *et al*. (2006), Leite *et al*. (2006), Mohd. *et al*. (2009), Mansour *et al.* (2012) and David and Smith

(2015), who reported similar results with the result of this study that whitefly eggs were more on tomato leaves due to higher number of adults on the leaves that lay more eggs and increase in abundance with the increase in environmental temperature and relative humidity. Lower oviposition was also recorded in the rainy season as a result of a reduction in abundance of the adults due the detrimental effects of the rains, this is in agreement with Mohd *et al*. (2009) who also stated that in Sudan heavy rains were usually followed by a drop in population levels of adult *B. tabaci* found that the oviposition was impaired by rains.

The lower egg abundance indicated low positive relationship with the relative humidity in the rainy season is supported by the findings of Khan *et al.* (2019), who found out that low humidity was as a result of higher *B. tabaci* mortality due to heavy rains in Israel, leading to lower oviposition rates and resulting to low egg production. However, the significant positive correlation between egg abundance and some weather factors tally with the result of Sharma *et al*. (2017), who stated that correlation between meteorological parameters and whitefly egg oviposition was negatively correlated with number of rainy days and total rainfall as also reported by Kaur *et al.*, (2020), which could be attributed to the destruction of eggs, nymphs and adults of *B. tabaci* during the heavy rains as reported by Mansour *et al*. (2012). The distribution of *B. tabaci* eggs varied according to the climatic factors mainly due to the high correlation of *B. tabaci* adults that normally live on the upper parts of tomato and hence lay most of their eggs on the upper canopy when climatic factors are favourable as also reported by Mohd. *et al*. (2009).

Bemisia tabaci been favoured by higher temperatures and relative humidity makes this insect to be one of the most damaging pests of tomato in the tudy area due to these favourable conditions, causing heavy yield losses by direct feeding and transmits geminivirus as reported by Palumbo *et al*. (2001): Toscano *et al*. (2002) and Willa Dunn *et al*. (2020). Environmental conditions are very important, in determining incidence and whitefly abundance that increase with increase in temperature, relative humidity and wind speed while decrease with increase in rainfall (Abdullahi *et al.*, 2004: Muhammad *et al*, 2017). Infestation leads to tomato yield reduction as reported by Mathur *et al*. (2012) that percent fruit infestation revealed a significant negative correlation with mean relative humidity. Earlier reports also confirmed that *B. tabaci* transmits *Tomato Yellow Leaf Curl Virus* (TYLCV) and physical effect caused by adult and nymphal feeding were attributed to causing irregular ripening of tomato fruits (Alawathungoda and Dahanyake, 2014: Alam *et al.*, 2016). Similarly, Degiri and Sani (2015) tomato production in the tropics such as Nigeria is constrained by a complex of insects with *B. tabaci* been among the most damaging insect pest on tomato crop.

6.7 Conclusion

The present investigation indicated *B. tabaci* abundance to be significantly higher in the dry seasons than in the rainy seasons. Weather parameters recorded (temperature, relative humidity and rainfall) collectively accounted for different percentage variations in adult, nymph and egg abundance as observed on tomato plants. The more the increase in temperature the more the *B. tabaci* abundance while the higher the rainfall the lower the abundance. *B. tabaci* as an insect pest significantly affected the performance of tomato by reducing its number of flower production, fruit production, thus reducing fruit yield and fruit quality and in tomato. Furthermore, a significant reduction in the number of fruits produced by tomato plants was attributed to the significantly higher *B. tabaci* infestation that decreased the number of tomato plants in the dry season than in the rainy season in the trial periods in both 2017 and 2018.

It could be concluded that seasonal abundance of *B. tabaci* insect pests in the study area is greatly influenced by certain climatic factors with the peak population of whitefly observed in the beginning of the dry seasons during the study period. Warmer temperatures were found to encourage more *B. tabaci* activities, fecundity and abundance in the study area during this study. These findings can pave way for a sustainable and effective integrated whitefly management and should be targeted from the Month of July onwards to prevent the pest build-up in September in the study area (Kebbi State) and this could probably help in excluding the times of peak *B. tabaci* population during tomato production in the field in the study location.

CHAPTER 7

SUMMARY, GENERAL CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

Field experiments were conducted in the dry and rainy seasons of 2017 and 2018 on the monitoring the incidence and abundance of some major insect pests of tomato plant with a particular emphasis on *B. tabaci* in the study location. Significantly higher number of insect pests were recorded in the dry seasons than in the rainy seasons of both 2017 and 2018 on tomato in the field. Results on seasonal abundance revealed *E. fabae* was significantly ($P<0.05$) the highest in abundance, next to it was *M. euphorbiae* and *B. tabaci* which recorded similar and came second in abundance on tomato in the experimental field. With the exception of the *E. hirtipennis* that gave the similar population in the two different seasons, significantly higher insect abundance ($P<0.05$) were recorded on most of the six major tomato pests monitored in the dry period more than that of the rainy season abundance particularly as recorded in *E. fabae, M. euphorbiae* and *B. tabaci*.

Mean weekly abundance revealed weekly population fluctuation on all the insect pests studied, while correlation matrix showed contrasting results existing between the respective insect abundance in relation to temperature, humidity and rainfall in dry as well as wet periods revealing different levels of relationships. *Bemisia tabaci* adults, nymphs and eggs recorded on tomato plants correlated positively with temperature and relative humidity in both season except with rainfall. A unit increase in temperature and humidity led to unit increase in *B. tabaci* abundance on tomato and positively correlated with both mean temperature, relative humidity but had negative relationship with rainfall. Result revealed that *B. tabaci* infestation reduced the performance of tomato by decreasing the number of flowers produced, decreasing the number of fruits produced and increased mortality including the number of irregular fruit ripening on tomato. *Bemisia tabaci* was found to be the most serious pest affecting tomato by reducing its quality and quantity in the study location.

7.1 General Conclusions

This work was undertaken to study the major insect pests of tomato with a particular emphasis on whitefly abundance in relation to the environmental factors at the research location as it relates to some of the key insect pests of tomato plant in order to obtain information that can be useful in the timing and effective insect pest control strategies in the integrated pest management. The experiment was conducted to monitor the presence, seasonal abundance and infestation of whitefly along with other major insect pests of tomato in both field and in the insect-proof nets. The study on seasonal abundance showed that these insect monitored particularly the whitefly abundance correlates significantly with both temperatures, relative humidity and rainfall. Seasonal abundance of the insect pests monitored was significantly influenced by these three seasonal factors and peak insect population levels were observed during the end of the rainy season and onset of the dry season periods.

The present investigation had indicated the significance of monitoring and assessments of insect pests of tomato, specifically *B. tabaci* in the field for proper timing of tomato insect pest control strategies, and signifies that it is of paramount importance to understand the times of higher insect pest abundance on tomato production seasons in Jega, Kebbi, Nigeria. It is crucial to have comprehensive information on climatic factors such as environmental temperature, relative humidity and an average rainfall of the agro-ecological environment in relation to their abundance, because of the mutual relationship existing between them. In this study, higher insect abundance was recorded in the dry season the highest whitefly adult, nymph and egg abundance. *B. tabaci* was found to be more abundant at the early onset of the dry seasons (October) when there is no or less rainfall and a rise in temperature, with favourable temperature regime, conducive relative humidity and readily available flush of vegetation to feed on.

Based on this study manual insect counts and the use of Yellow Sticky Traps proved efficient in determining insect pests including *B. tabaci* abundance on tomato. Monitoring should commence early before the population build-up in the Months of July-August in the late rainy season times and March-April in the early dry seasons in the study area. Whitefly been the most injurious among the insect pest assessed on tomato is best controlled prior to infestation on tomato in the farms, this is to avoid or significantly reduce the spread of the viral diseases transmitted by this insect during feeding on tomato plants during infestation.

7.2 Recommendations

- Based on these findings it is recommended that timing of *B. tabaci* control strategies should be carried out before it reaches its peak population build-up specifically before the tail end of rainy season periods and towards the beginning of the dry seasons in the study area as this will substantially assists in bringing down the population of *B. tabaci* to the lowest level in the study location.
- It is recommended that Leafhopper control sterategies should be initiated in the tudy site as it recorded the highest abundance as the pest can be a source of concerns in tomato production in the study site.

- It is also recommended that future researches should be conducted to further monitor and assess other possible devastating insect pests of tomato that were likely not available during the two year's trial periods in this study and include different tomato varieties in order to widen the scope of the search to have a broader perspective of the various insect pest problems on tomato in the study area.

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APPENDICES

Appendix A.1 : Abundace of Insect Pest Species on Tomato as Affected by Dry Seasons in 2017 and 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	321.9453125	321.9453125	495.87	<.0001
Block	3	0.7109375	0.2369792	30.33	0.3096
Error	3	0.0234375	0.0078125		
Corrected Total	7	322.6796875			

Appendix A.2 : Abundance of Insect Pest Species on Tomato in the Rainy Season of 2017

Source	DF	ANOVA SS	Mean Squre	F Value	P> F
SEASON	1	549.344221	549.344221	22.95	0.0001
INSECTS	5	7677.765097	2047.865097	92.87	<.0001
SEASON*INSECTS	5	546.810374	230.564432	5.81	0.0026
REP	3	13.887760	6.767749	1.43	0.8976

Appendix A.3 : Abundance of Insect Pest Species on Tomato in the Dry and Rainy Seasons of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	1451.257813	1451.257813	252.97	0.0005
Block	3	16.898438	5.632813	0.98	0.5058
Error	3	17.210938	5.736979		
Corrected Total	7	1485.367188			

Appendix A.4 : Abundance of Insect Pest Species on Tomato in the Dry and Rainy Seasons of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	1451.257813	1451.257813	252.97	0.0005
Block	3	16.898438	5.632813	0.98	0.5058
Error	3	17.210938	5.736979		
Corrected Total	7	1485.367188			

Appendix A.5 : Relationship of Temperature and Relative Humididty towards the Abundance of Insect Species on Tomato in the Dry Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	P> F
Season	1	439.230000	439.230000	18.60	0.0001
Insects	5	9659.691667	1931.938333	81.79	<.0001
Season*Insects	5	546.762500	109.352500	4.63	0.0026
Block	3	13.967500	4.655833	0.20	0.8976

Appendix A.6 : Relationship of Temperature and Relative Humididty towards the Abundance of Insect Species on Tomato in the Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	321.9453125	321.9453125	41209.0	<.0001
Block	3	0.7109375	0.2369792	30.33	0.0096
Error	3	0.0234375	0.0078125		
Corrected Total	7	322.6796875			

Appendix A.7 : Two-Way ANOVA Layout for Insect Abundance in the Rainy Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Season	1	14.630208	14.630208	1.12	0.0172
Insects	5	6913.733542	1782.746708	136.72	<.0001
Season*Insects	5	411.49333542	82.298708	6.31	0.0003
Block	3	126.237292	42.07999097	3.23	0.0943

Appendix A.8 : One Way ANOVA Output for *B. tabaci* Abundance on Tomato in the Dry Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	328.3203125	328.3203125	44.47	0.0069
Block	3	39.4609375	13.1536458	1.78	0.3235
Error	3	22.1484375	7.3828125		
Corrected Total	7	389.9296875			

Appendix A.9 : One Way ANOVA Output for *B. tabaci* Abundance on Tomato in the Rainy Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	556.9453125	556.9453125	379.87	0.0003
Block	3	16.2734375	5.4244792	3.70	0.1555
Error	3	4.3984375	1.4661458		
Corrected Total	7	577.6171875			

Appendix A.10 : One Way ANOVA Output for *B. tabaci* Abundance on Tomato in the Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	887.2578125	887.2578125	51.35	0.0056
Block	3	33.2109375	11.0703125	0.64	0.6383
Error	3	51.8359375	17.2786458		
Corrected Total	7	972.3046875			

Appendix A.11 : One Way ANOVA Output for *B. tabaci* Abundance on Tomato in the Rainy Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	1451.257813	1451.257813	252.97	0.0005
Block	3	16.898438	5.632813	0.98	0.5058
Error	3	17.210938	5.736979		
Corrected Total	7	1485.367188			

Appendix A.12 : ANOVA Output for Mean Weekly *M. euphorbiae* Abundance on Tomato in the Dry Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	51.25781250	51.25781250	4.93	0.0131
Block	3	28.27343750	9.42447917	0.91	0.5314
Error	3	31.2109375	10.4036458		
Corrected Total	7	110.7421875			

Appendix A.13 : ANOVA Output for Mean Weekly *M. euphorbiae* Abundance on Tomato in the Rainy Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	347.8203125	347.8203125	55.40	0.0050
Block	3	47.3359375	15.7786458	2.51	0.2345
Error	3	18.8359375	6.2786458		
Corrected Total	7	413.9921875			

Appendix A.14 : ANOVA Output for Mean Weekly *M. euphorbiae* Abundance on Tomato in the Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	595.1250000	595.1250000	179.66	0.0009
Block	3	4.3125000	1.4375000	0.43	0.7446
Error	3	9.9375000	3.3125000		
Corrected Total	7	609.3750000			

Appendix A.15 : ANOVA Output for Mean Weekly *M. euphorbiae* Abundance on Tomato in the Rainy Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	142.3828125	142.3828125	36.87	0.0090
Block	3	17.7109375	5.9036458	1.53	0.3679
Error	3	11.5859375	3.8619792		
Corrected Total	7	171.6796875			

Appendix A.16 : ANOVA Output for *E. fabae* Abundance in the Dry Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	556.9453125	556.9453125	379.87	0.0003
Block	3	16.2734375	5.4244792	3.70	0.1555
Error	3	4.3984375	1.4661458		
Corrected Total	7	577.6171875			

Appendix A.17 : ANOVA Output for *E. fabae* Abundance in the Rainy Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	267.3828125	267.3828125	168.04	0.0010
Block	3	14.0234375	4.6744792	2.94	0.1999
Error	3	4.7734375	1.5911458		
Corrected Total	7	286.1796875			

Appendix A.18 : ANOVA Output for *E. fabae* Abundance in the Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	548.6328125	548.6328125	99.23	0.0022
Block	3	13.2734375	4.4244792	0.80	0.5705
Error	3	16.5859375	5.5286458		
Corrected Total	7	578.4921875			

Appendix A.19 : ANOVA Output for *E. fabae* Abundance in the Rainy Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	361.1328125	361.1328125	68.41	0.0037
Block	3	15.1484375	5.0494792	0.96	0.5141
Error	3	15.8359375	5.2786458		
Corrected Total	7	392.1171875			

Appendix A.20 : ANOVA Output for *E hirtipenis* Abundance in the Dry Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	4.50000000	4.50000000	9.39	0.0548
Block	3	0.90625000	0.30208333	0.63	0.6431
Error	3	1.43750000	0.47916667		
Corrected Total	7	6.84375000			

Appendix A.21 : ANOVA Output for *E hirtipenis* Abundance in Rainy Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	4.88281250	4.88281250	25.00	0.0154
Block	3	0.39843750	0.13281250	0.68	0.6205
Error	3	0.58593750	0.19531250		
Corrected Total	7	5.86718750			

Appendix A.22 : ANOVA Output for *E hirtipenis* Abundance in Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	693.7812500	693.7812500	435.31	0.0002
Block	3	4.5625000	1.5208333	0.95	0.5149
Error	3	4.7812500	1.5937500		
Corrected Total	7	703.1250000			

Appendix A.23 : ANOVA Output for *E hirtipenis* Abundance in Rainy Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	321.9453125	321.9453125	41209.0	<.0001
Block	3	0.7109375	0.2369792	30.33	0.0096
Error	3	0.0234375	0.0078125		
Corrected Total	7	322.6796875			

Appendix A.24 : ANOVA Output for *P. solenopsi* Abundance in Dry Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	166.5312500	166.5312500	20.79	0.0198
Block	3	18.3125000	6.1041667	0.76	0.5857
Error	3	24.0312500	8.0104167		
Corrected Total	7	208.8750000			

Appendix A.25 : ANOVA Output for *P. solenopsi* Abundance in Rainy Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	25.38281250	25.38281250	16.60	0.0267
Block	3	4.02343750	1.34114583	0.88	0.5416
Error	3	4.58593750			
Corrected Total	7				

Appendix A.26 : ANOVA Output for *P. solenopsi* Abundance in Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	87.78125000	87.78125000	48.71	0.0060
Block	3	6.18750000	2.06250000	1.14	0.4571
Error	3	5.40625000	1.80208333		
Corrected Total	7	99.37500000			

Appendix A.27 : ANOVA Output for *P. solenopsi* Abundance in Rainy Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	43.94531250	43.94531250	16.18	0.0276
Block	3	7.46093750	2.48697917	0.92	0.5280
Error	3	8.14843750	2.71614583		
Corrected Total	7	59.55468750			

Appendix A.28 : ANOVA Output for *H. amigera* Abundance in Dry Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	29.07031250	29.07031250	65.28	0.0040
Block	3	3.08593750	1.02864583	2.31	0.2548
Error	3	1.33593750	0.44531250		
Corrected Total	7	33.49218750			

Appendix A.29 : ANOVA Output for *H. amigera* Abundance in Rainy Season of 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.07031250	0.07031250	0.27	0.6376
Block	3	0.14843750	0.04947917	0.19	0.8958
Error	3	0.77343750	0.25781250		
Corrected Total	7	0.99218750			

Appendix A.30 : ANOVA Output for *H. amigera* Abundance in Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.07031250	0.07031250	0.53	0.0195
Block	3	0.89843750	0.29947917	2.25	0.2608
Error	3	0.39843750	0.13281250		
Corrected Total	7	1.36718750			

Appendix A.31 : ANOVA Output for *H. amigera* Abundance in Rainy Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.63281250	0.63281250	5.65	0.0479
Block	3	0.39843750	0.13281250	1.19	0.4459
Error	3	0.33593750	0.11197917		
Corrected Total	7	1.36718750			

Appendix A.32 : ANOVA Output for Insect Abundance in the Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	524.0703125	524.0703125	174.24	0.0009
Block	3	56.5234375	18.8411458	6.26	0.0830
Error	3	9.0234375	3.0078125		
Corrected Total	7	589.6171875			

Appendix A.33 : ANOVA Output for Insect Abundance in the Dry Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	3.44531250	3.44531250	1.65	0.0395
Block	3	0.96093750	0.32031250	0.15	0.9212
Error	3	6.27343750	2.09114583		
Corrected Total	7	10.67968750			

Appendix A.34 : Output for Insect Abundance in the Rainy Season of 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	8.00000000	8.00000000	4.86	0.0147
Block	3	5.28125000	1.76041667	1.07	0.4786
Error	3	4.93750000	1.64583333		
Corrected Total	7	18.21875000			

Appendix A.35 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.63281250	0.63281250	5.65	0.039
Block	3	0.39843750	0.13281250	1.19	0.4459
Error	3	0.33593750	0.11197917		
Corrected Total	7	1.36718750			

Appendix A.36 : ANOVA Output for Mean Weekly Abundance on Tomato in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	1.53125000	1.53125000	3.27	0.0184
Block	3	0.93750000	0.31250000	0.67	0.6265
Error	3	1.40625000	0.46875000		
Corrected Total	7	3.87500000			

Appendix A.37 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.42013889	0.42013889	0.94	0.4042
Block	3	0.67708333	0.22569444	0.50	0.7061
Error	3	1.34375000	0.44791667		
Corrected Total	7	2.44097222			

Appendix A.38 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.00781250	0.00781250	0.02	0.9052
Block	3	0.39843750	0.13281250	0.28	0.8350
Error	3	1.39843750	0.46614583		
Corrected Total	7	1.80468750			

Appendix A.39 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.03125000	0.03125000	0.27	0.0376
Block	3	0.34375000	0.11458333	1.00	0.5000
Error	3	0.34375000	0.11458333		
Corrected Total	7	0.71875000			

Appendix A.40 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.00781250	0.00781250	0.05	0.8361
Block	3	0.71093750	0.23697917	1.54	0.3652
Error	3	0.46093750	0.15364583		
Corrected Total	7	1.17968750			

Appendix A.41 : ANOVA Output for Mean Weekly on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.12500000	0.12500000	2.00	0.2522
Block	3	0.15625000	0.05208333	0.83	0.5578
Error	3	0.18750000	0.06250000		
Corrected Total	7	0.46875000			

Appendix A.42 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.78125000	0.78125000	15.00	0.0305
Block	3	0.28125000	0.09375000	1.80	0.3206
Error	3	0.15625000	0.05208333		
Corrected Total	7	1.21875000			

Appendix A.43 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	1.75781250	1.75781250	4.35	0.1282
Block	3	0.46093750	0.15364583	0.38	0.7757
Error	3	1.21093750	0.40364583		
Corrected Total	7	0.40364583			

Appendix A.44 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	334.7578125	334.7578125	58.14	0.0047
Block	3	3.9609375	1.3203125	0.23	0.8712
Error	3	17.2734375	5.7578125		
Corrected Total	7	355.9921875			

Appendix A.45 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	200.0000000	200.0000000	139.13	0.0013
Block	3	13.3125000	4.4375000	3.09	0.1897
Error	3	4.3125000	1.4375000		
Corrected Total	7	217.6250000			

Appendix A.46 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	159.7578125	159.7578125	9.16	0.0565
Block	3	26.4609375	8.8203125	0.51	0.7052
Error	3	52.3359375	17.4453125		
Corrected Total	7	238.5546875			

Appendix A.47 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	105.1250000	105.1250000	29.86	0.0120
Block	3	21.5625000	7.1875000	2.04	0.2864
Error	3	10.5625000	3.5208333		
Corrected Total	7	137.2500000			

Appendix A.48 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	105.1250000	105.1250000	8.93	0.0582
Block	3	13.5625000	4.5208333	0.38	0.7737
Error	3	35.3125000	11.7708333		
Corrected Total	7	154.0000000			

Appendix A.49 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	225.7812500	225.7812500	656.82	0.0001
Block	3	6.0312500	2.0104167	5.85	0.0905
Error	3	1.0312500	0.3437500		
Corrected Total	7	232.8437500			

Appendix A.50 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	220.5000000	220.5000000	94.50	0.0023
Block	3	18.6250000	6.2083333	2.66	0.2214
Error	3	7.0000000	2.3333333		
Corrected Total	7	246.1250000			

Appendix A.51 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	136.1250000	136.1250000	27.92	0.0132
Block	3	4.3437500	1.4479167	0.30	0.8273
Error	3	14.6250000	4.8750000		
Corrected Total	7	155.0937500			

Appendix A.52 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	180.5000000	180.5000000	29.17	0.0124
Block	3	3.4375000	1.1458333	0.19	0.9002
Error	3	18.5625000	6.1875000		
Corrected Total	7	202.5000000			

Appendix A.53 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	185.2812500	46.9843750	30.30	0.0118
Block	3	12.3750000	4.1250000	0.67	0.6229
Error	3	18.3437500	6.1145833		
Corrected Total	7	216.0000000			

Appendix A.54 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	205.0312500	205.0312500	35.85	0.0093
Block	3	4.8125000	1.6041667	0.28	0.8379
Error	3	17.1562500	5.7187500		
Corrected Total	7	227.0000000			

Appendix A.55 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	67.57031250	67.57031250	5.35	0.1038
Block	3	81.64843750	27.21614583	2.15	0.2723
Error	3	37.8984375	12.6328125		
Corrected Total	7	187.1171875			

Appendix A.56 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2017

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	101.5312500	101.5312500	2.58	0.2063
Block	3	97.8437500	32.6145833	0.83	0.5589
Error	3	117.8437500	39.2812500		
Corrected Total	7	317.2187500			

Appendix A.57 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	940.6953125	940.6953125	106.90	0.0019
Block	3	17.5859375	5.8619792	0.67	0.6267
Error	3	26.3984375	8.7994792		
Corrected Total	7	984.6796875			

Appendix A.58 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	138.1953125	138.1953125	9.75	0.0524
Block	3	86.3359375	28.7786458	2.03	0.2878
Error	3	42.5234375	14.1744792		
Corrected Total	7	267.0546875			

Appendix A.59 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	136.1250000	136.1250000	13.28	0.0356
Block	3	81.0937500	27.0312500	2.64	0.2234
Error	3	30.7500000	10.2500000		
Corrected Total	7	247.9687500			

Appendix A.60 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	225.7812521	25.8812500	745.65.	<.0001.
Block	3	17.12500000	5.70833333	31.87	0.0818
Error	3	4.28125000	14.1744792		
Corrected Total	7	267.0546875			

Appendix A.61 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	148.7812500	148.7812500	10.80	0.0462
Block	3	185.1250000	61.7083333	4.48	0.1249
Error	3	41.3437500	13.7812500		
Corrected Total	7	375.2500000			

Appendix A.62 : ANOVA Output for Mean Weekly Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	28.12500000	28.12500000	2.45	0.2152
Block	3	83.34375000	27.78125000	2.42	0.2430
Error	3	34.3750000	11.4583333		
Corrected Total	7	145.8437500			

Appendix A.63 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	12.5000000	12.5000000	2.00	0.2522
Block	3	131.6250000	43.8750000	7.02	0.0719
Error	3	18.7500000	6.2500000		
Corrected Total	7	162.8750000			

Appendix A.64 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.50000000	0.50000000	0.39	0.5750
Block	3	40.06250000	13.35416667	10.51	0.0423
Error	3	3.81250000	1.27083333		
Corrected Total	7	44.37500000			

Appendix A.65 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	63.28125000	63.28125000	2.45	0.2152
Block	3	64.12500000	21.37500000	0.83	0.5594
Error	3	77.3437500	25.7812500		
Corrected Total	7	204.7500000			

Appendix A.66 : ANOVA Output for Mean Weekly Insect Abundance on Tomato in the Experimental Field in 2018

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	0.2812500	0.2812500	0.05	0.8373
Block	3	100.0937500	33.3645833	5.94	0.0887
Error	3	16.8437500	5.6145833		
Corrected Total	7	117.2187500			

Appendix B

ANOVA Output for Regression and Correlation on Major Insect Abundance on Tomato in Relation to Climatic Factors in the Field

Appendix B.1 : ANOVA on Aphid, *M. euphorbiae* Abundance in Relation to Temperature and Humidity in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	2	55.74097	27.87049	0.626746	0.012
Residual	9	400.2169	44.46855		
Total	11	455.9579			

Appendix B.2 : ANOVA on Aphid, *M. euphorbiae* Abundance in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	23.44644	7.815481	3.056112	0.0197
Residual	8	20.45862	2.557328		
Total	11	43.90507			

Appendix B.3 : ANOVA on Fruit Worm, *H. armigera* Abundance in Relation to Temperature and Humidity in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	2	0.216186	0.108093	0.795658	0.0306
Residual	9	1.222681	0.135853		
Total	11	1.438867			

Appendix B.4 : ANOVA on Fruit Worm, *H. armigera* Abundance in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	67.63041	22.54347	0.757738	0.0154
Residual	8	238.008	29.751		
Total	11	305.6384			

Appendix B.5 : ANOVA on Flea Beetle, *E. hirtipennis* Abundance in Relation to Temperature and Humidity in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	2	0.117994	0.058997	0.54342	0.0187
Residual	9	0.977097	0.108566		
Total	11	1.095092			

Appendix B.6 : ANOVA on Flea Beetle, *E. hirtipennis* Abundance in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	0.32763	0.10921	1.937229	0.0422
Residual	8	0.450995	0.056374		
Total	11	0.778625			

Appendix B.7 : ANOVA on Mealy Bug, *P. solenopsi* Abundance in Relation to Temperature and Humidity in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	2	9.251236	4.625618	4.34491	0.04779
Residual	9	9.581456	1.064606		
Total	11	18.83269			

Appendix B.8 : ANOVA on Mealy Bug, *P. solenopsi* Abundance in Relation to Temperature, Humidity and Rainfall in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	2.536423	0.845474	0.972191	0.0452
Residual	8	6.957269	0.869659		
Total	11	9.493692			

Appendix B.9 : ANOVA on Leafhopper, *E. fabae* Abundance in Relation to Temperature and Humidity in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	2	190.5504	95.2752	3.508209	0.0175
Residual	9	244.4201	27.15779		
Total	11	434.9705			

Appendix B.10 : ANOVA on Leafhopper, *E. fabae* Abundance in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	127.5185	42.50615	4.732384	0.0349
Residual	8	71.8558	8.981975		
Total	11	199.3743			

Appendix B.11 : ANOVA on Whitefly, *B. tabaci* Abundance in Relation to Temperature and Humidity in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	2	1079.279	539.6395	7.831101	0.0107
Residual	9	620.188	68.90978		
Total	11	1699.467			

Appendix B.12 : ANOVA on Whitefly, *B. tabaci* Abundance in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	11.89602	3.965341	1.13092	0.03929
Residual	8	28.05038	3.506297		
Total	11	39.9464			

Appendix C

ANOVA output for whitefly, *B. tabaci* abundance in relation to climatic factors in the field in 2018

Appendix C.1 : ANOVA on Whitefly, *B. tabaci* Abundance in Relation to Temperature and Humidity in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	2	286.1916	286.1916	2.019219	0.0125
Residual	9	1417.338	141.7338		
Total	11	1703.53			

Appendix C.2 : ANOVA on Whitefly, *B. tabac*i Abundance in Relation Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	1.132419	1.132419	0.29467	0.0129
Residual	8	38.43008	3.843008		
Total	11	39.5625			

Appendix C.3 : ANOVA: Number of Leaf Damaged Per Plant

Source	DF	Anova Sum of Squares	Mean Square	F Value	Pr > F
Block	2	15.50000000	7.75000000	2.13	0.2000
Season	1	70.08333333	70.08333333	19.26	0.0046
Leaf damage	1	18.75000000	18.75000000	5.15	0.0637
Season*Leaf damage	1	0.08333333	0.08333333	0.02	0.8847
Error	6	21.8333333	3.6388889		
Corrected Total	1	126.2500000			

Appendix C.4 : ANOVA: Number of Plant Mortality Per Plot

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Block	2	0.6666667	0.3333333	3.00	0.1250
Season	1	27.0000000	27.0000000	243.00	<.0001
Mortality	1	320.3333333	320.3333333	2883.00	<.0001
Season*mortality	1	48.0000000	48.0000000	432.00	<.0001
Error	6	0.6666667	0.1111111		
Corrected Total	11	396.6666667			

Appendix C.5 : ANOVA: Number of Flowers Per Plant Per Plant

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Block	2	34.6666667	17.3333333	1.24	0.3547
Season	1	850.0833333	850.0833333	60.72	0.0002
Flowers per plant	1	752.0833333	752.0833333	53.72	0.0003
Season*flowers	1	990.0833333	990.0833333	70.72	0.0002
Error	6	84.000000	14.000000		
Corrected Total	11	2710.916667			

Appendix C.6 : ANOVA: Number of Fruit Per Plant

Source	DF	Anova Sum of Squares	Mean Square	F Value	Pr > F
Block	2	0.666667	0.333333	0.43	0.6699
Season	1	1140.750000	1140.750000	1466.68	<.0001
Fruit damage	1	660.083333	660.083333	848.68	<.0001
Season*fruit damage	1	90.750000	90.750000	116.68	<.0001
Error	6	4.666667	0.777778		
Corrected Total	11	1896.916667			

Appendix C.7 : ANOVA for *B. tabaci* Adult Abundance on Tomato in the Net House in Relation to Temperature and Humidity in the Dry Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	2	6.962231	2.320744	3.707973	0.0213
Residual	9	5.007035	0.625879		
Total	11	11.96927			

Appendix C.8 : ANOVA for *B. tabaci* Adult Abundance on Tomato in the Net House in Relation to Temperature and Humidity in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	0.329625	0.109875	0.701181	0.0473
Residual	8	1.2536	0.1567		
Total	11	1.583225			

Appendix C.9 : ANOVA for *B. tabaci* Adult Abundance on Tomato in the Net House in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	0.070904	0.023635	0.143091	0.0312
Residual	8	1.321387	0.165173		
Total	11	1.392292			

Appendix C.10 : ANOVA for *B. tabaci* Nymph Abundance on Tomato in the Net House in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	0.16173	0.05391	0.448329	0.0253
Residual	8	0.96197	0.120246		
Total	11	1.1237			

Appendix C.11 : ANOVA for *B. tabaci* Nymph Abundance on Tomato in the Net House in Relation to Temperature, Humidity and Rainfall In the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	11.19979	3.733264	1.616204	0.0267
Residual	8	18.47918	2.309897		
Total	11	29.67897			

Appendix C.12 : ANOVA for *B. tabaci* Nymph Abundance on Tomato in the Net House in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	4.41896	1.472987	1.180026	0.0374
Residual	8	9.986132	1.248266		
Total	11	14.40509			

Appendix C.13 : ANOVA for *B. tabaci* Egg Abundance on Tomato in the Net House in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	13.96614	4.655379	4.299127	0.0439
Residual	8	8.662929	1.082866		
Total	11	22.62907			

Appendix C.14 : ANOVA for *B. tabaci* Egg Abundance on Tomato in the Net House in Relation to Temperature, Humidity and Rainfall in the Rainy Season

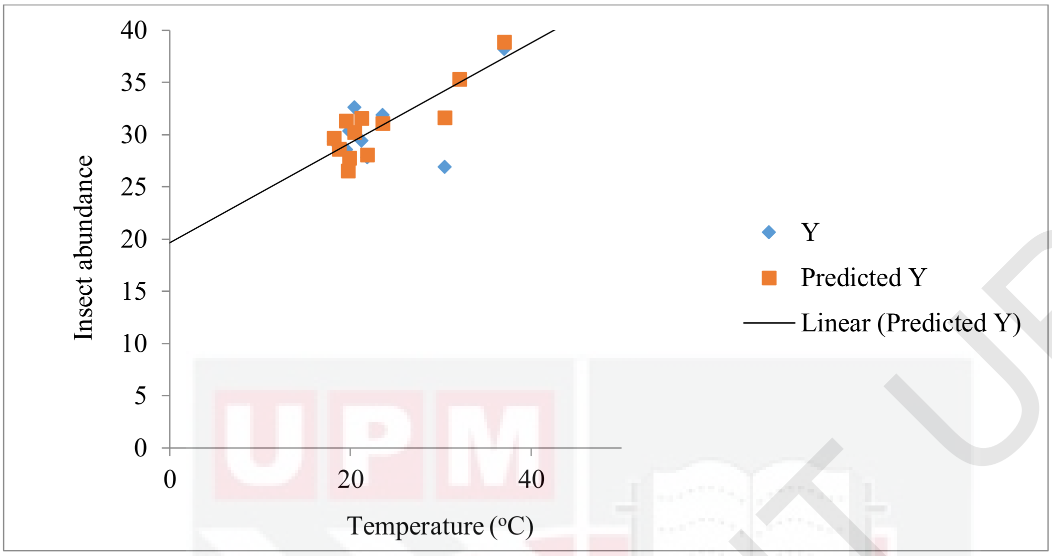
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	0.934412	0.311471	1.632922	0.0252
Residual	8	1.525955	0.190744		
Total	11	2.460367			

Appendix C.15 : ANOVA for *B. tabaci* Egg Abundance on Tomato in the Net House in Relation to Temperature, Humidity and Rainfall in the Rainy Season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Regression	3	0.112762	0.037587	0.640052	0.0102
Residual	8	0.469804	0.058726		
Total	11	0.582567			

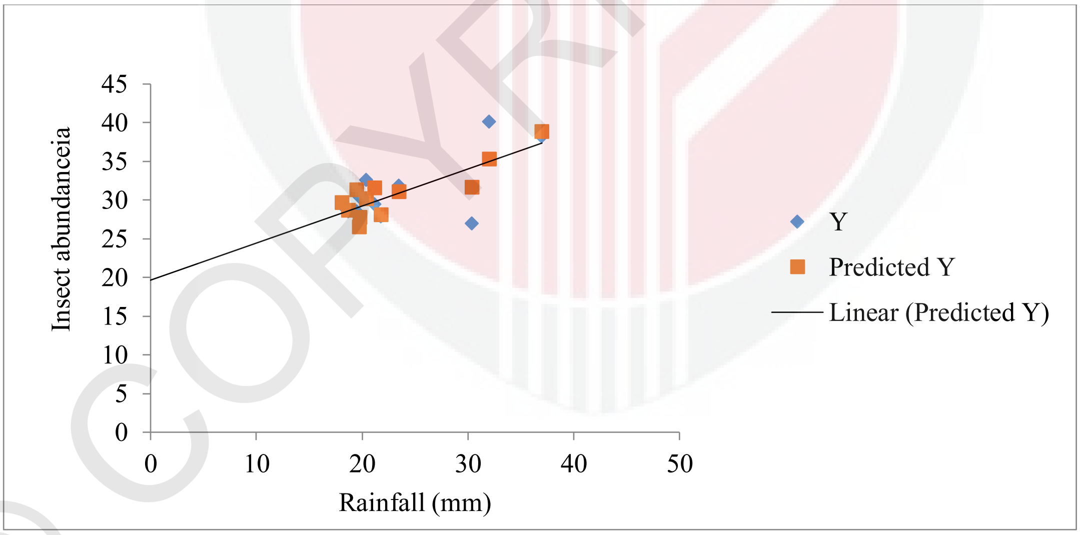
Appendix D

$Y = 0.479x+19.661$ ($R^2 = 0.748$)



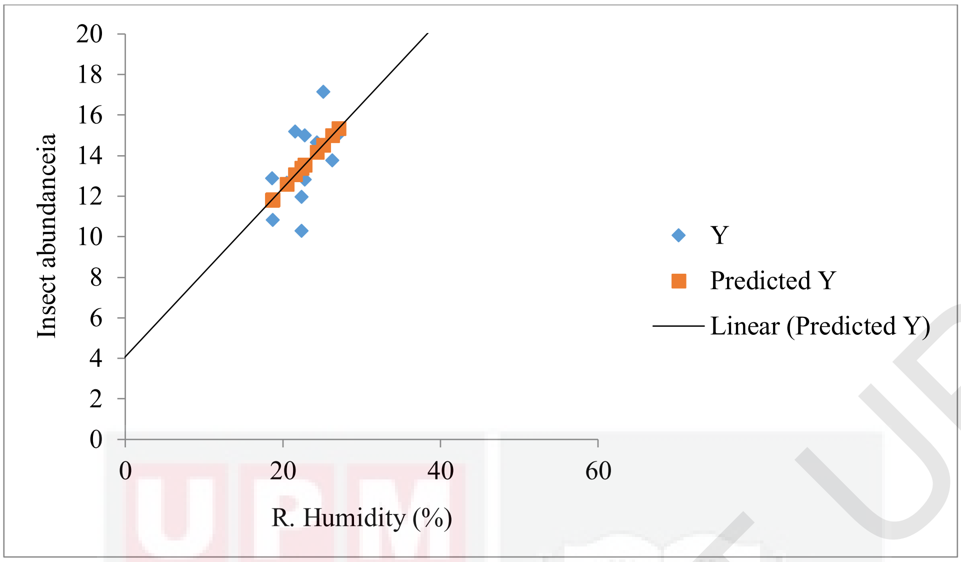
Appendix Figure D.1 : Relationship between Insect Abundance and Temperature in the Dry Seasons of 2017 and 2018

$Y = 0.468x + 18.659$ ($R^2 = 0.714$)



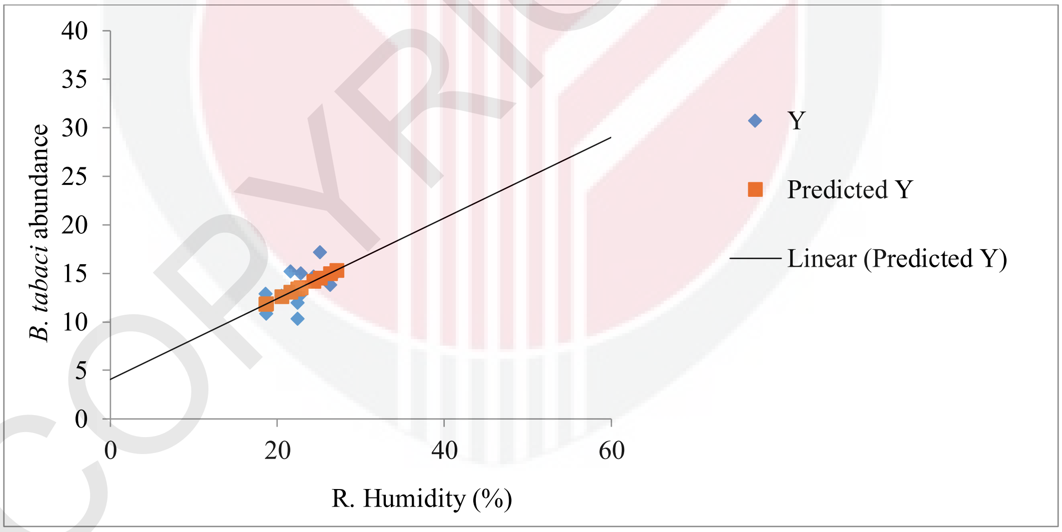
Appendix Figure D.2 : Relationship between Insect Abundance and Temperature in the Rainy Seasons of 2017 and 2018

$Y = 0.414x + 4.059$ ($R^2 = 0.988$)



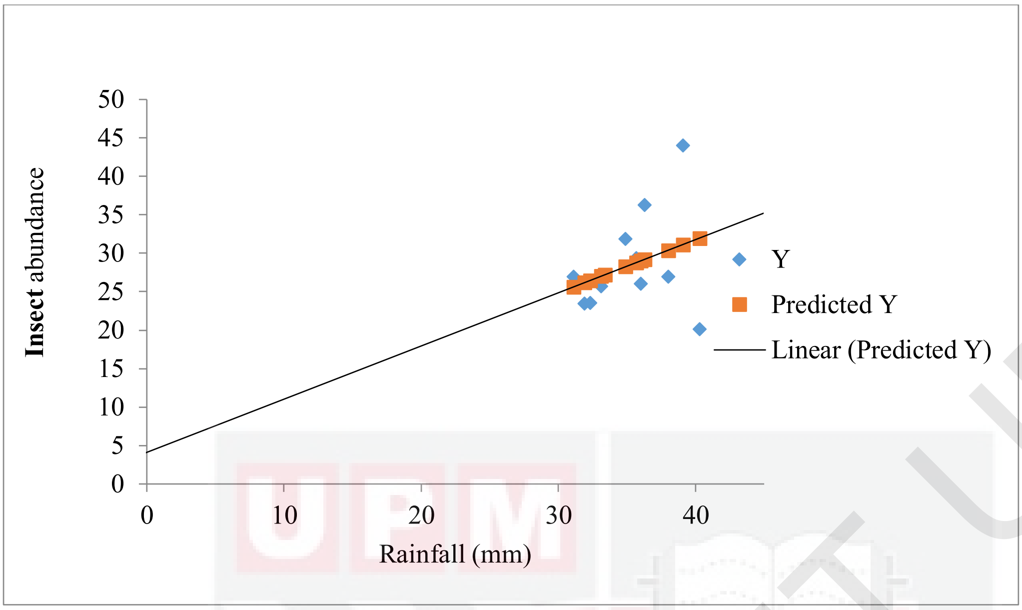
Appendix Figure D.3 : Relationship between Insect Abundance and Relative Humidity in the Dry Seasons of 2017 and 2018

$Y = 0.679x + 1.670$ ($R^2 = 0.965$)



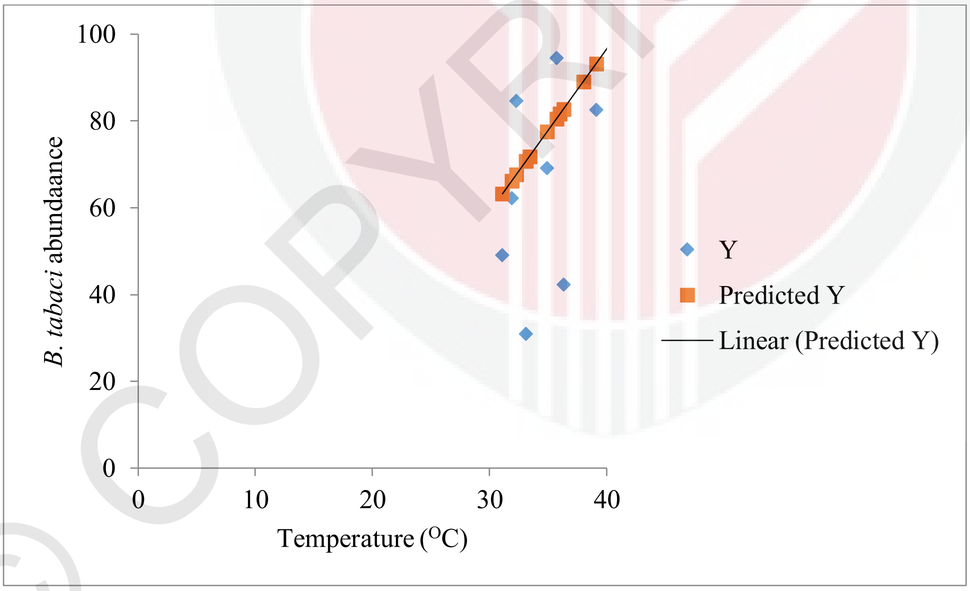
Appendix Figure D.4 : Relationship between Insect Abundance and Relative Humidity in the Rainy Seasons of 2017 and 2018

$Y = 0.691x + 4.113$ ($R^2 = 0.565$)



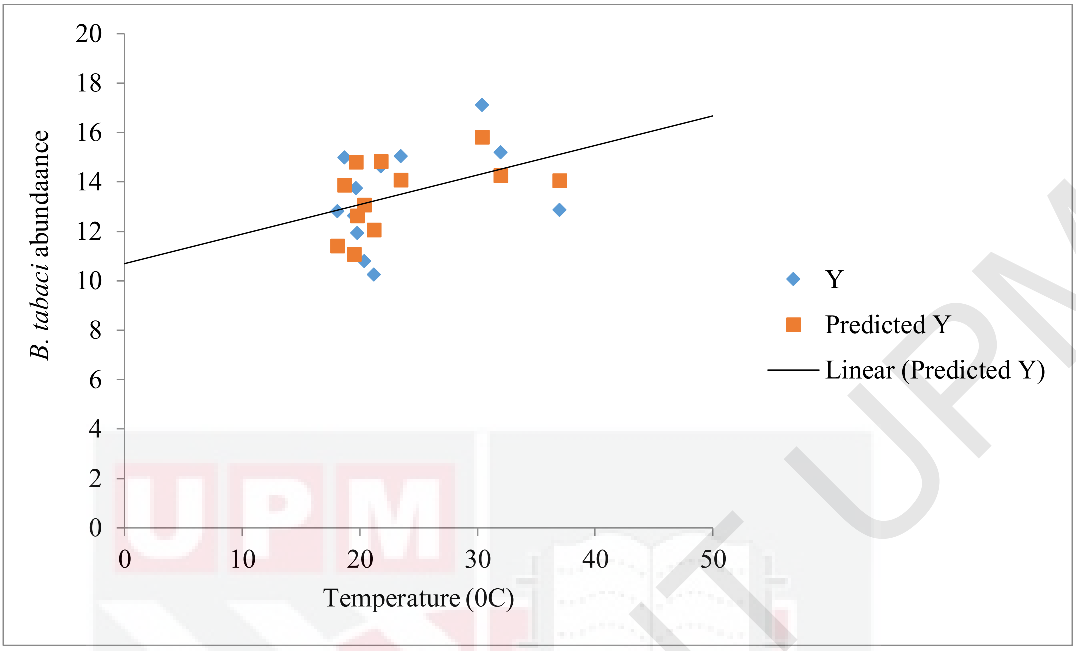
Appendix Figure D.5 : Relationship between Insect Abundance and Rainfall in the Rainy Seasons of 2017 and 2018

$Y = 0.713x + 7.231$ ($R^2 = 0.927$)



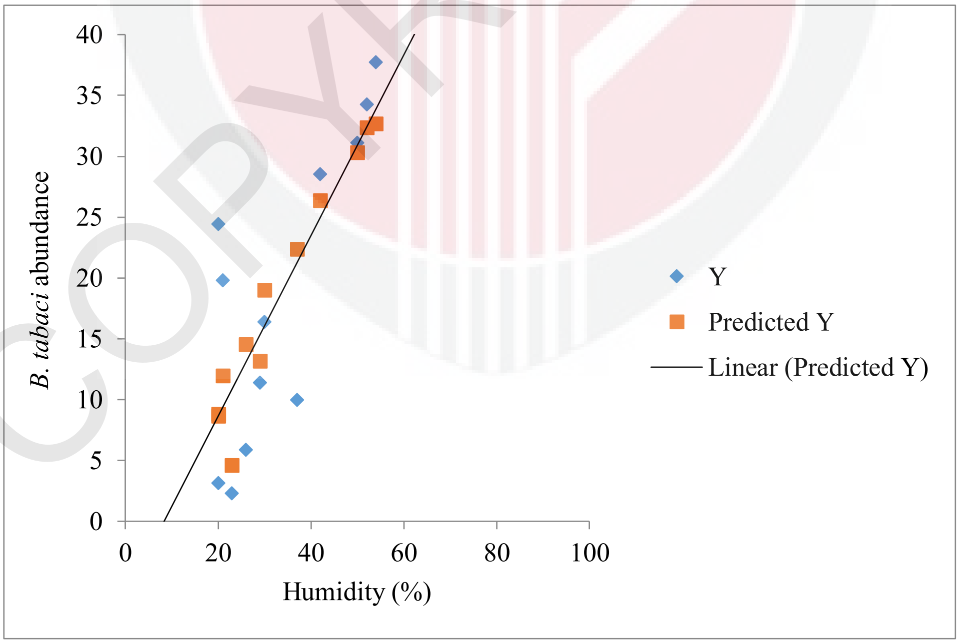
Appendix Figure D.6 : Relationship between *B. tabaci* Abundance and Temperature in the Dry Seasons of 2017 and 2018

Y= 0.118x + 10.790 (R^2 = 0.532)



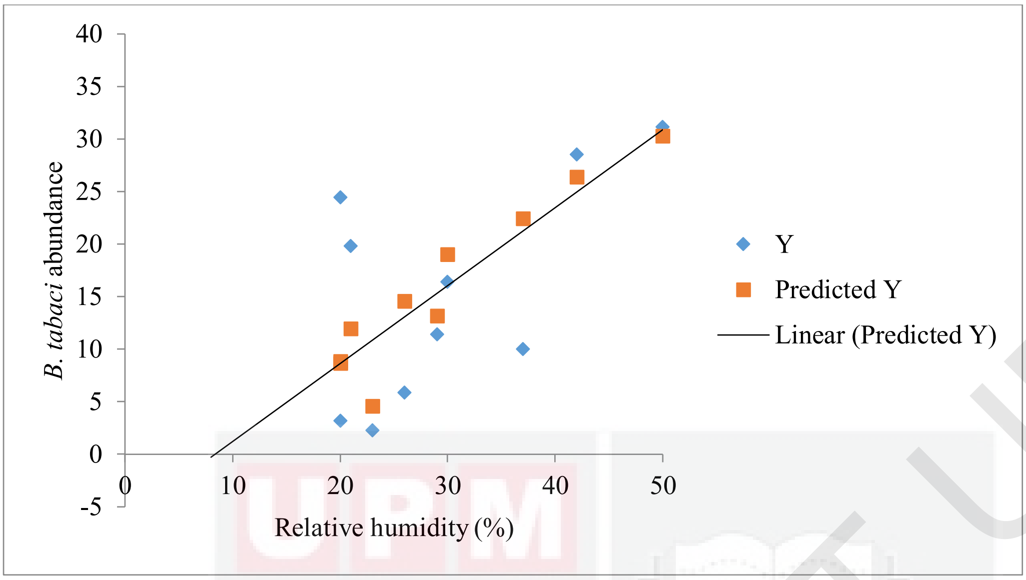
Appendix Figure D.7 : Relationship between *B. tabaci* Abundance and Temperature in the Rainy Seasons of 2017 and 2018

Y = 11.742x + 6.331 (R^2 = 0.946)



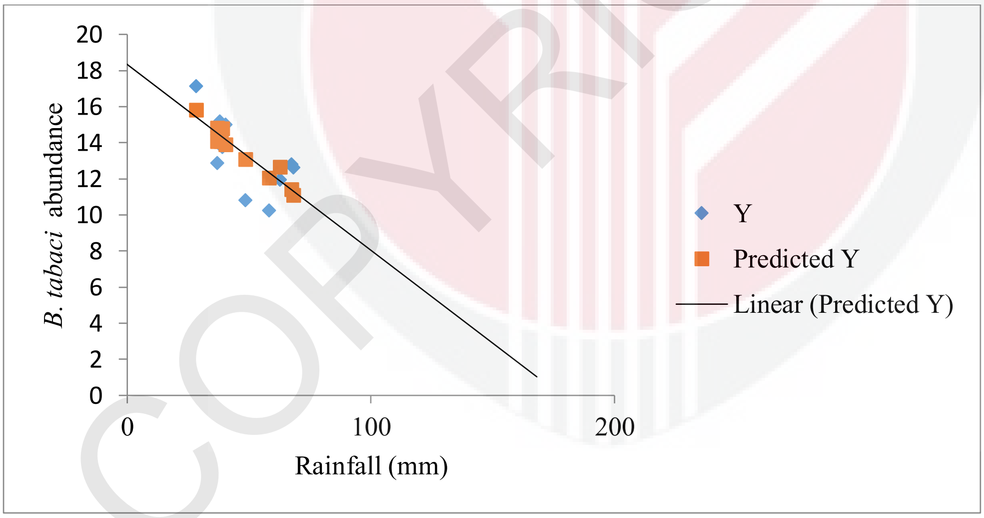
Appendix Figure D.8 : Relationship between *B. tabaci* Abundance and Relative Humidity in the Dry Seasons of 2017 and 2018

$Y = 0.743x - 6.231$ ($R^2 = 0.914$)



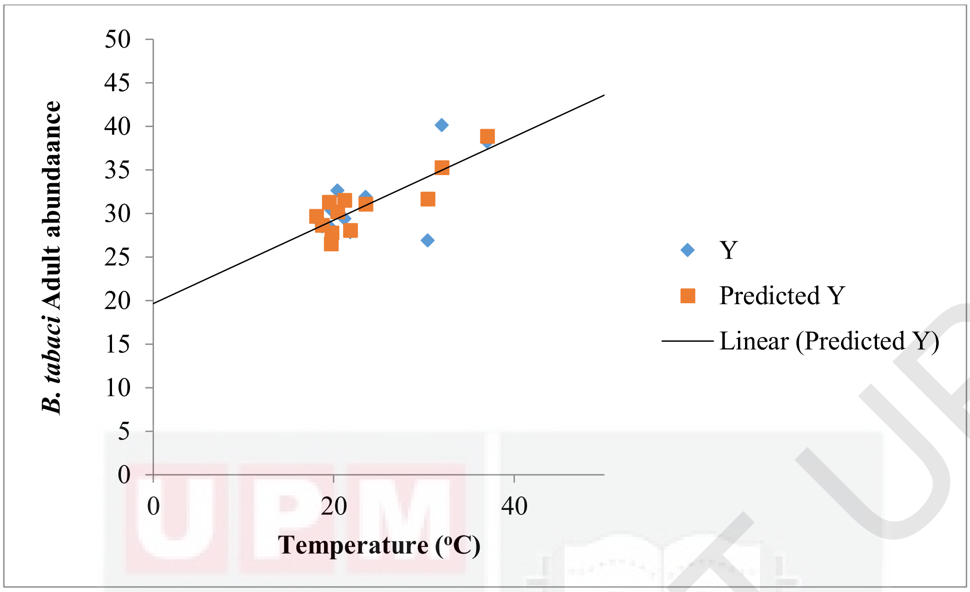
Appendix Figure D.9 : Relationship between *B. tabaci* Abundance and Relative Humidity in the Rainy Seasons of 2017 and 2018

$Y = -0.103x + 18.333$ ($R^2 = -0.925$)



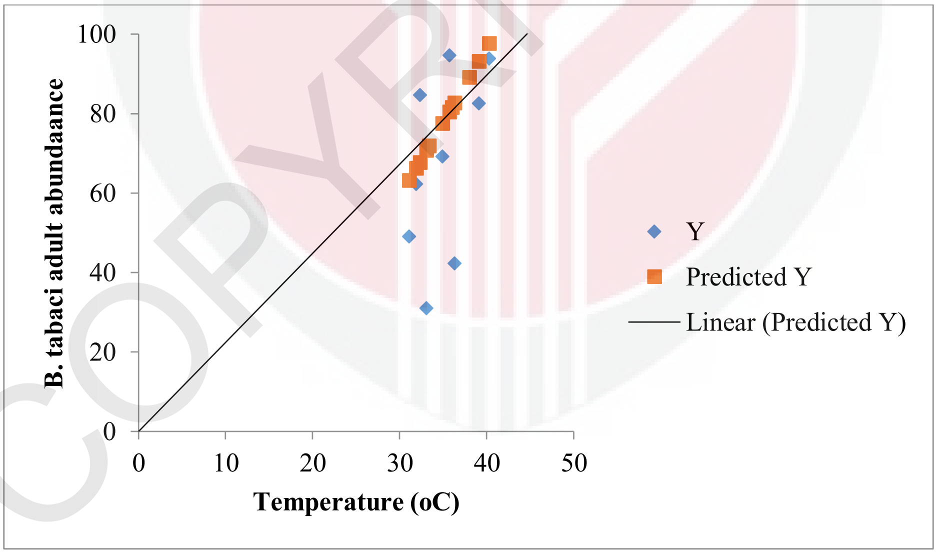
Appendix Figure D.10 : Relationship between *B. tabaci* Abundance and Rainfall in the Rainy Seasons of 2017 and 2018

$Y = 0.478x + 19.659$ ($R^2 = 0.748$)



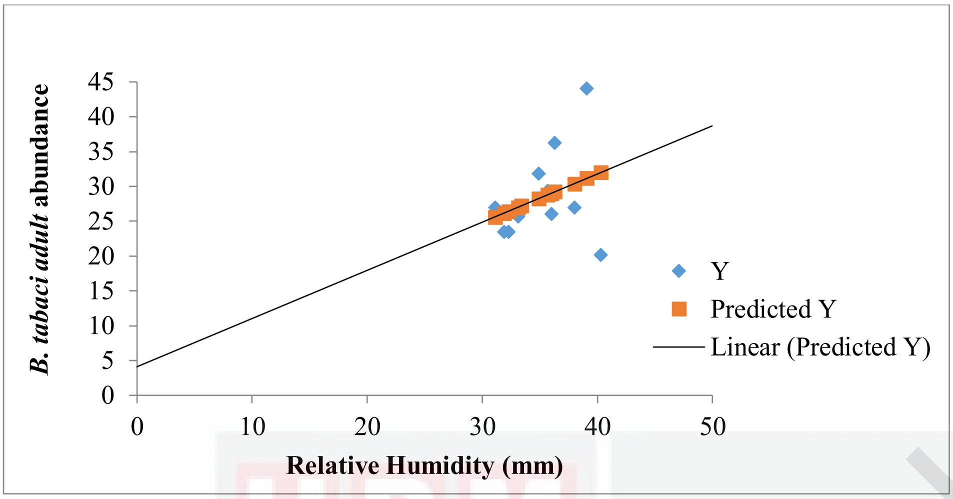
Appendix Figure D.11 : *B. tabaci* Adult Abundance on Tomato in the Covered Net Plots as Affected by Temperature in the Dry Seasons of 2017 and 2018

$Y = 2.267x + 20.255$ ($R^2 = 0.842$)



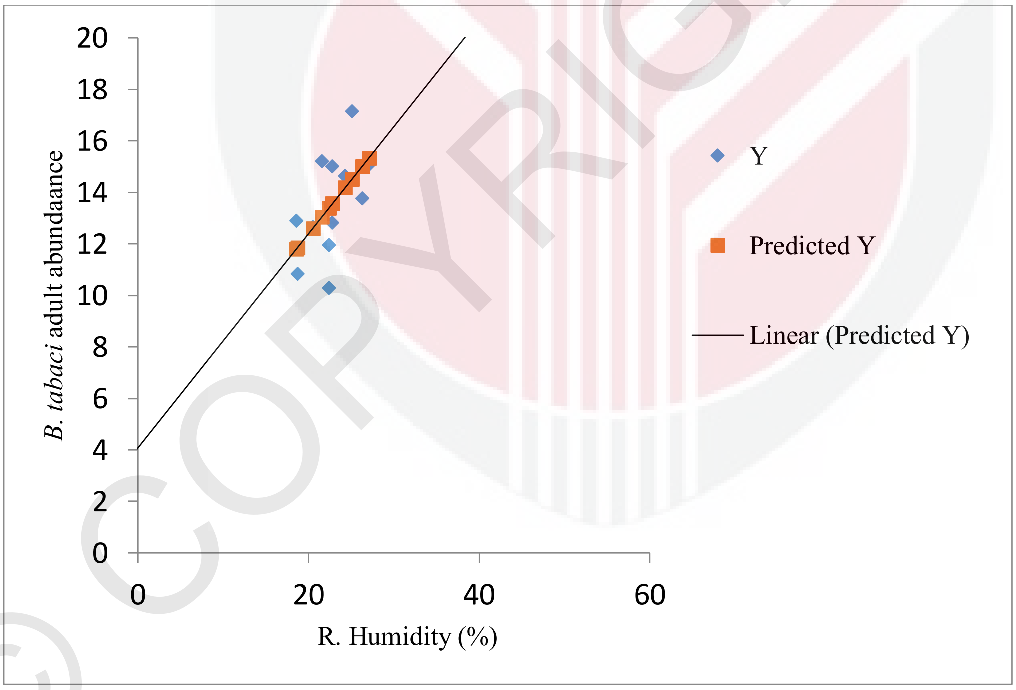
Appendix Figure D.12 : *B. tabaci* Adult Abundance on Tomato in the Covered Net Plots as Affected by Temperature in the Rainy Seasons of 2017 and 2018

$Y = 0.678x + 1.665$ ($R^2 = 0.976$)



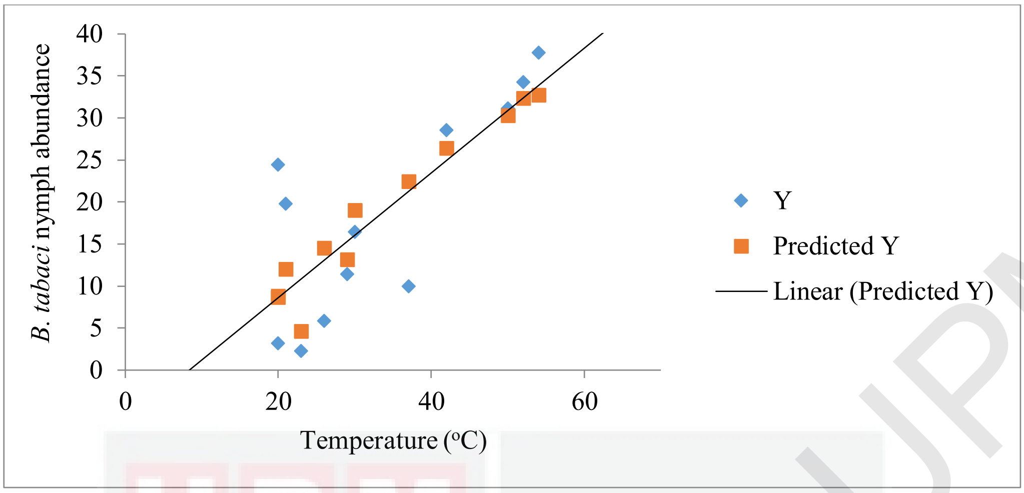
Appendix Figure D.13 : *B. tabaci* Adult Abundance on Tomato as Affected by R. Humidity in the Covered Net Plots in Dry Season of 2017 and 2018

$Y = 0.432x + 4.076$ ($R^2 = 0.973$)



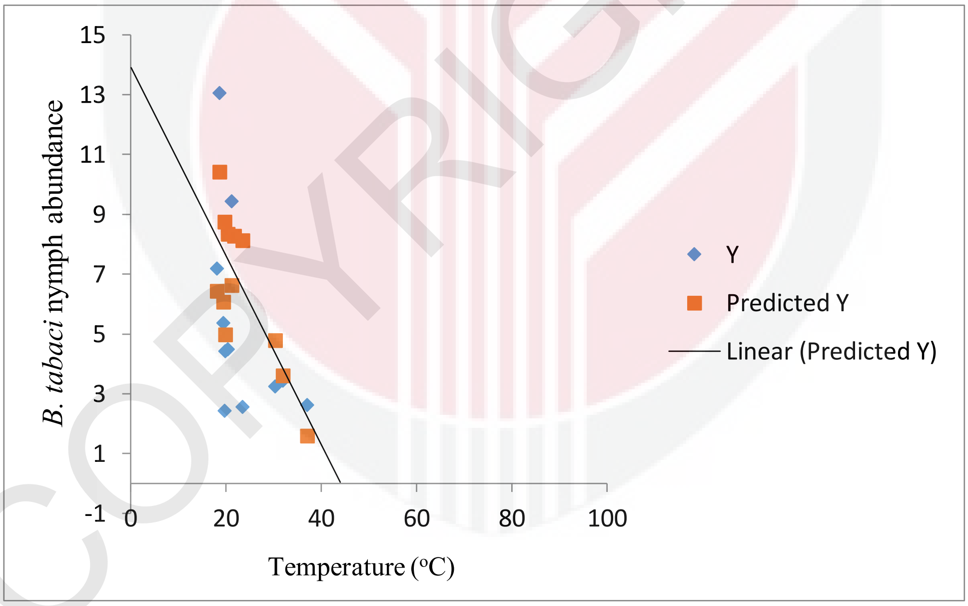
Appendix Figure D.14 : *B. tabaci* Adult Abundance on Tomato as Affected by R. Humidity in the Covered Net Plots in Rainy Seasons of 2017 and 2018

$Y = 0.741x - 6.211$ ($R^2 = 0.936$)



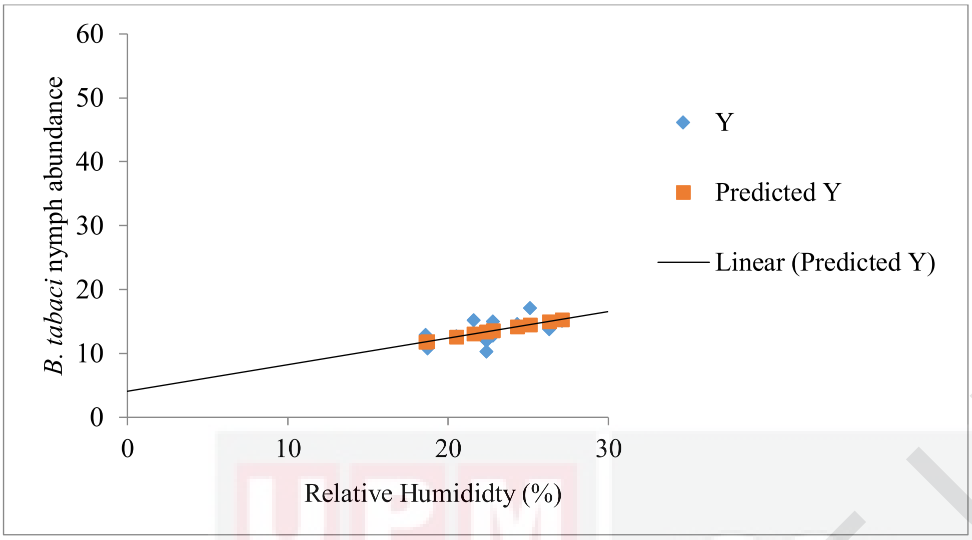
Appendix Figure D.15 : *B. tabaci* Nymph Abundance on Tomato as Affected by Temperature in the Covered Net Plots in Dry Seasons of 2017 and 2018

$Y = -0.316x + 13.935$ ($R^2 = 0.614$)



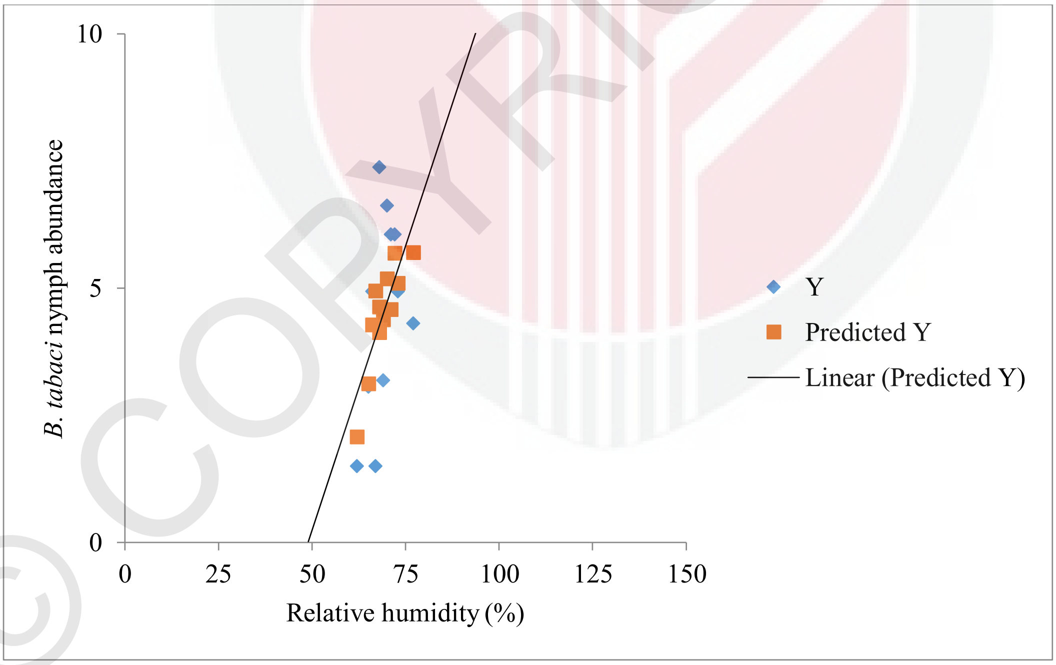
Appendix Figure D.16 : *B. tabaci* Nymph Abundance on Tomato as Affected by Temperature in the Covered Net Plots in the Rainy Seasons of 2017 and 2018

$Y = 0.416x + 4.659$ ($R^2 = 0.565$)



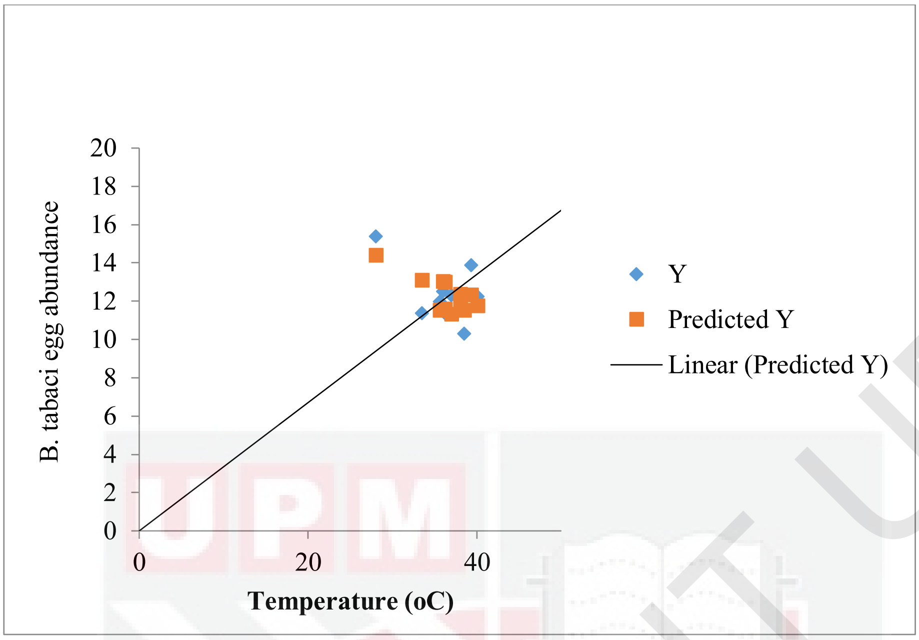
Appendix Figure D.17 : *B. tabaci* Nymph Abundance on Tomato as Affected by the Relative Humidity in the Covered Net Plots in the Dry Seasons of 2017 and 2018

$Y = 0.235x + 10.951$ ($R^2 = 0.746$)



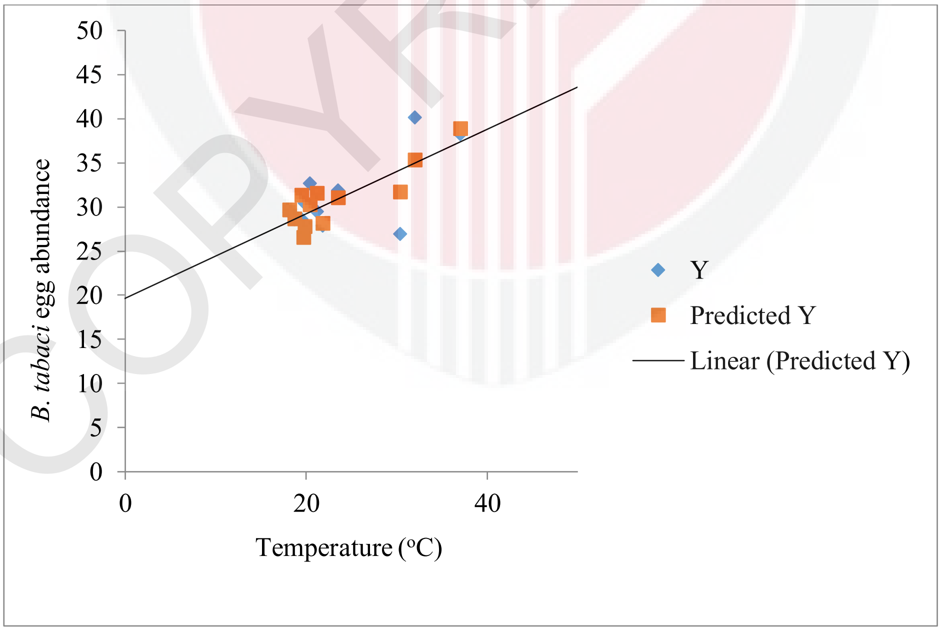
Appendix Figure D.18 : *B. tabaci* Nymph Abundance on Tomato as Affected by the Relative Humidity in the Covered Net Plots in Rainy Seasons of 2017 and 2018

Y = 0.217x + 20.276 (R^2 = 0.586)



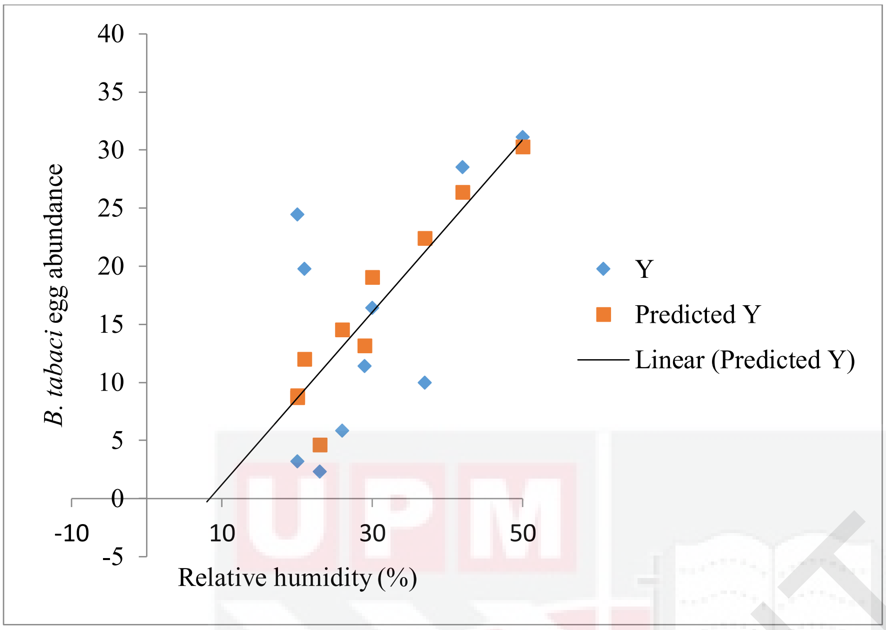
Appendix Figure D.19 : *B. tabaci* Egg Abundance on Tomato as Affected by Temperature in the Covered Net Plots in dry Season of 2017 and 2018

= 0.489x + 19.630 (R^2 = 0.736)



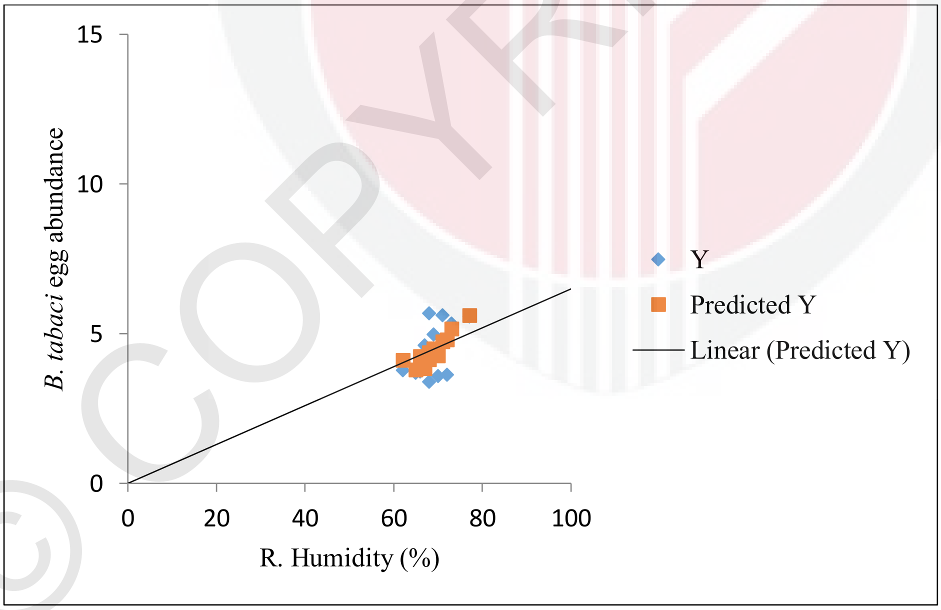
Appendix Figure D.20 : *B. tabaci* Egg Abundance on Tomato as Affected by Temperature in the Covered Net Plots in Rainy Season of 2017 and 2018

$Y = 0.743x - 6.182$ ($R^2 = 0.923$)



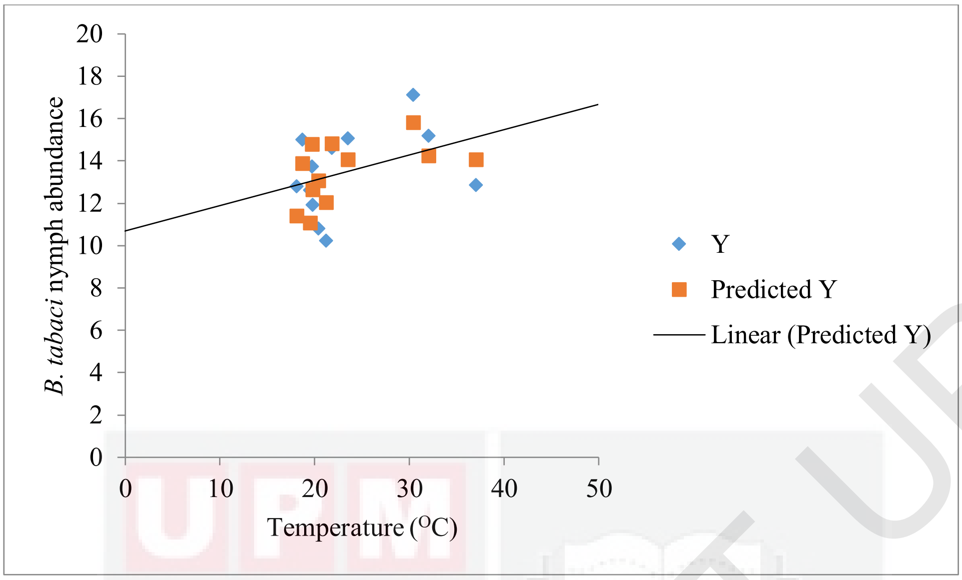
Appendix Figure D.21 : *B. tabaci* Egg Abundance on Tomato as Affected by Humidity in the Covered Net Plots in the Dry Seasons of 2017 and 2018

$Y = 0128.x - 3.657$ ($R^2 = 0.778$)



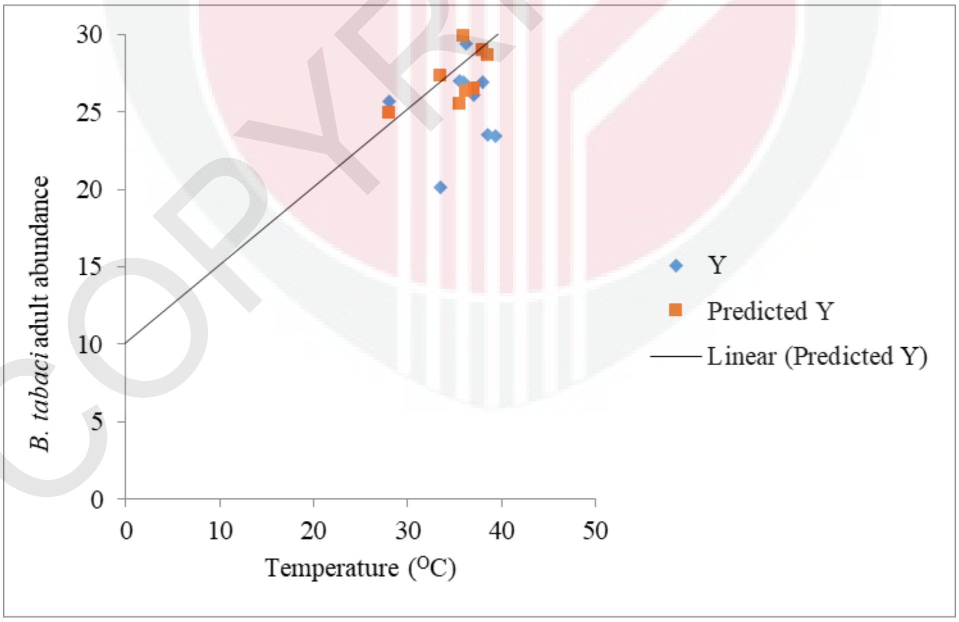
Appendix Figure D.22 : *B. tabaci* Egg Abundance on Tomato as Affected by Humidity in the Covered Net Plots in the Rainy Seasons of 2017 and 2018

$Y = 0.321x + 33.652$ ($R^2 = 0.531$)



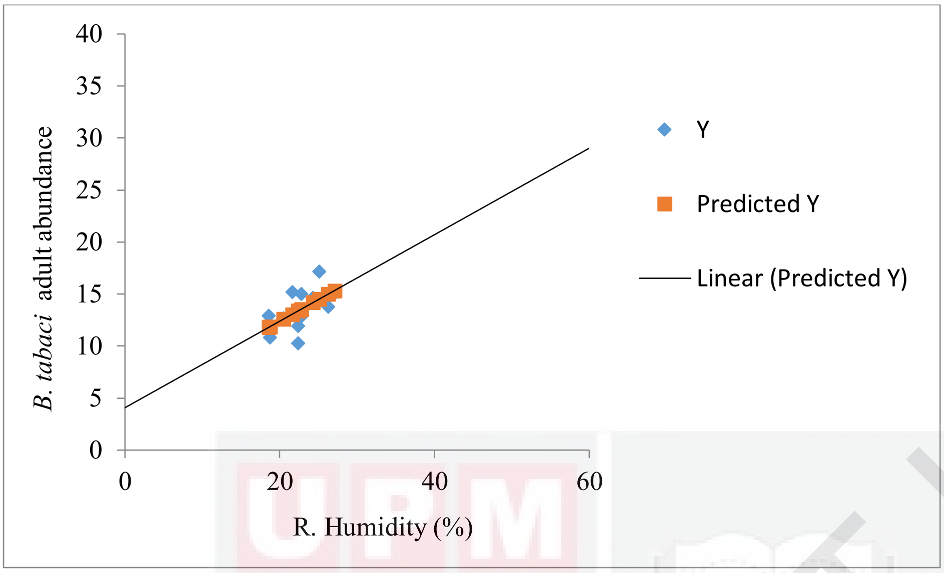
Appendix Figure D.23 : Relationship of Climatic Factors with *B. tabaci* Adult Seasonal Abundance on Tomato as Affected by Temperature in the Dry Seasons of 2017 and 2018

$Y = 0.503x + 10.165$ ($R^2 = 0.518$)



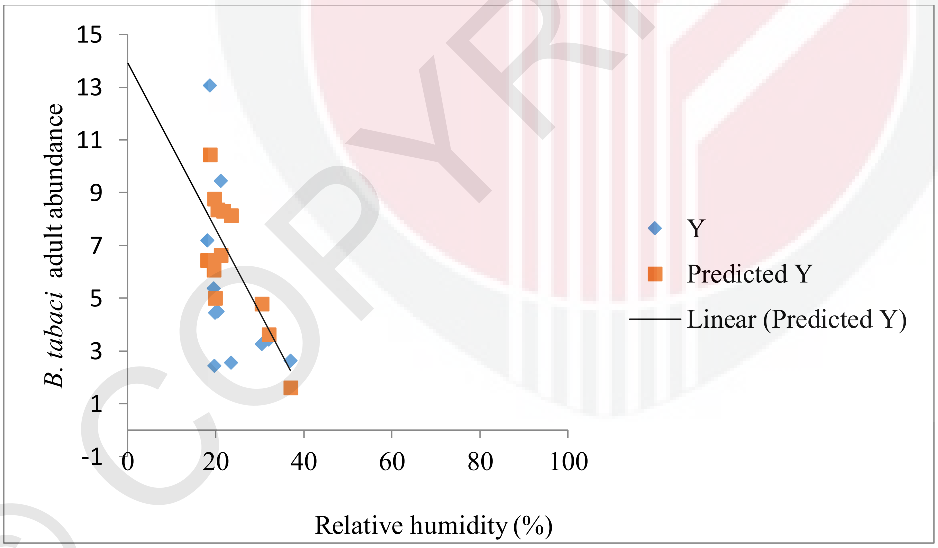
Appendix Figure D.24 : Relationship of Climatic Factors with *B. tabaci* Adult Seasonal Abundance on Tomato as Affected by Temperature in Rainy Seasons of 2017 and 2018

$Y = 0.424x + 4.073$ ($R^2 = 0.868$)



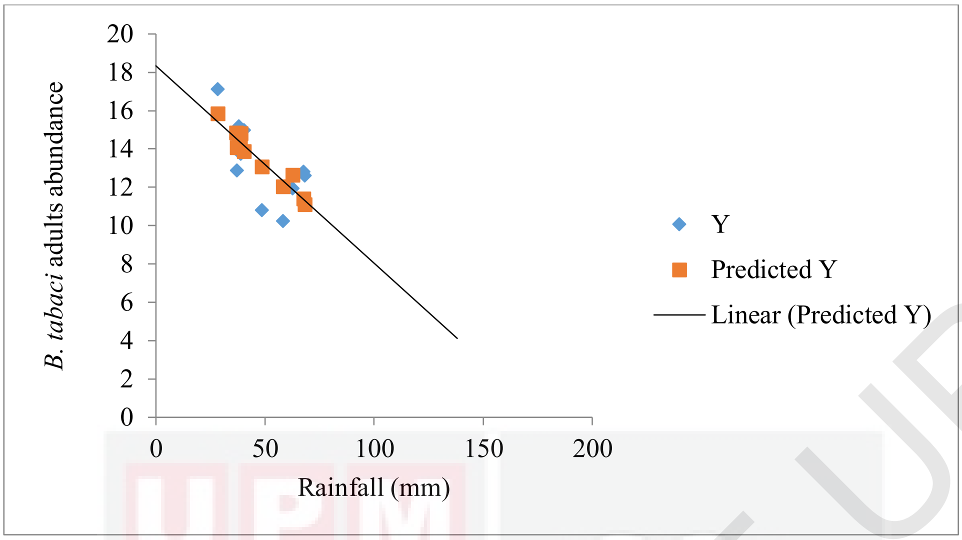
Appendix Figure D.25 : Relationship of Climatic Factors with *B. tabaci* Adult Seasonal Abundance on Tomato as Affected by Relative Humidity in Dry Season of 2017 and 2018

$Y = -0.326x + 1.384$ ($R^2 = -0.622$)



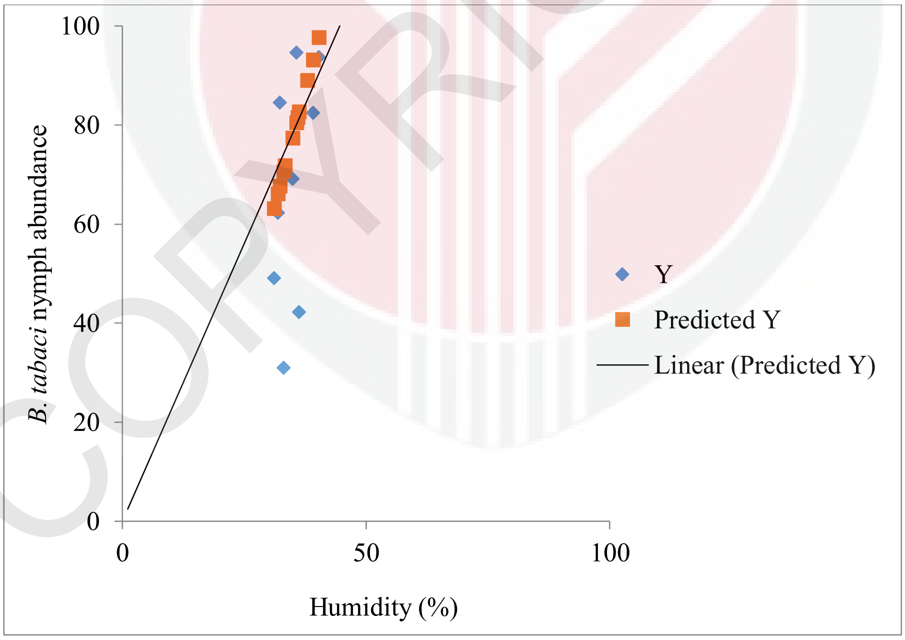
Appendix Figure D.26 : Relationship of Climatic Factors with *B. tabaci* Adult Seasonal Abundance on Tomato as Affected by Relative Humidity in Rainy Seasons of 2017 and 2018

$Y = -0.478x + 19.659$ ($R^2 = -0.748$)



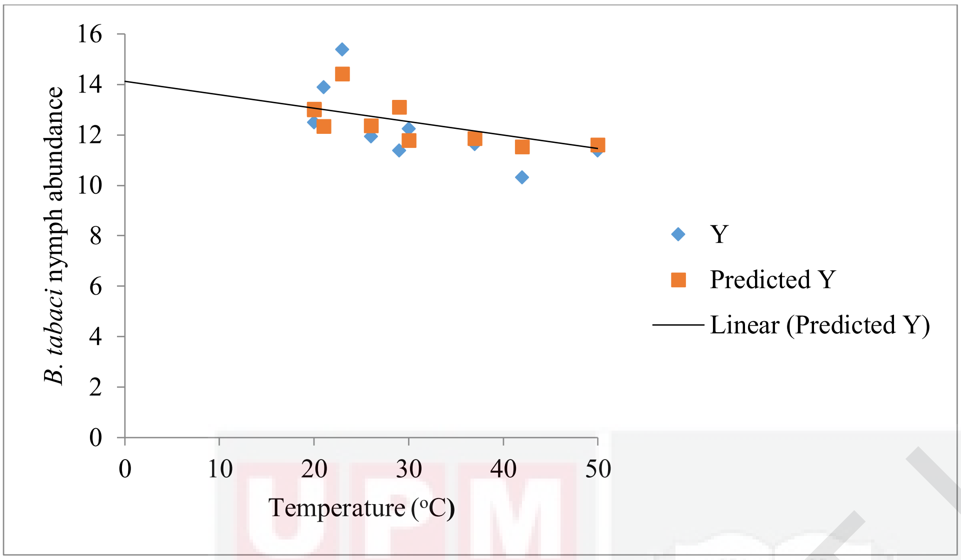
Appendix Figure D.27 : Relationship of Climatic Factors with *B. tabaci* Adult Seasonal Abundance on Tomato as Affected by Rainfall in the Rainy Seasons of 2017 and 2018

$Y = -2.241x + 33.65$ ($R^2 = 0.835$)



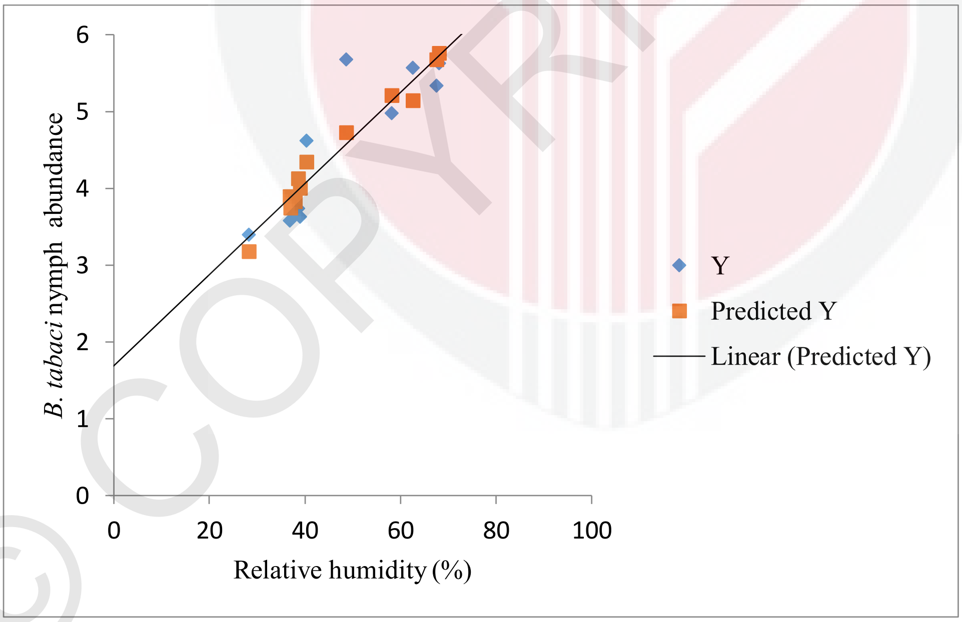
Appendix Figure D.28 : Relationship of Climatic Factors with *B. tabaci* Nymph Abundance on Tomato as Affected by Temperature in the Dry Seasons of 2017 and 2018

$Y = -0.532x + 30.861$ ($R^2 = -0.475$)



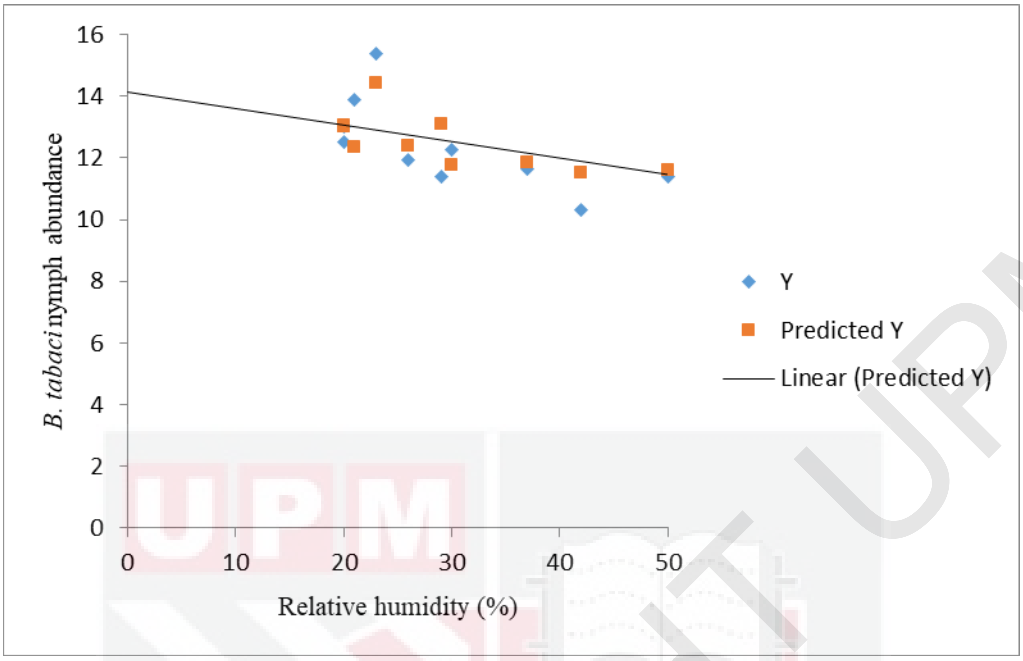
Appendix Figure D.29 : Relationship of Climatic Factors with *B. tabaci* Nymph Abundance on Tomato as Affected by Temperature in the Rainy Seasons of 2017 and 2018

$Y = 0.058x + 1.652$ ($R^2 = 0.975$)



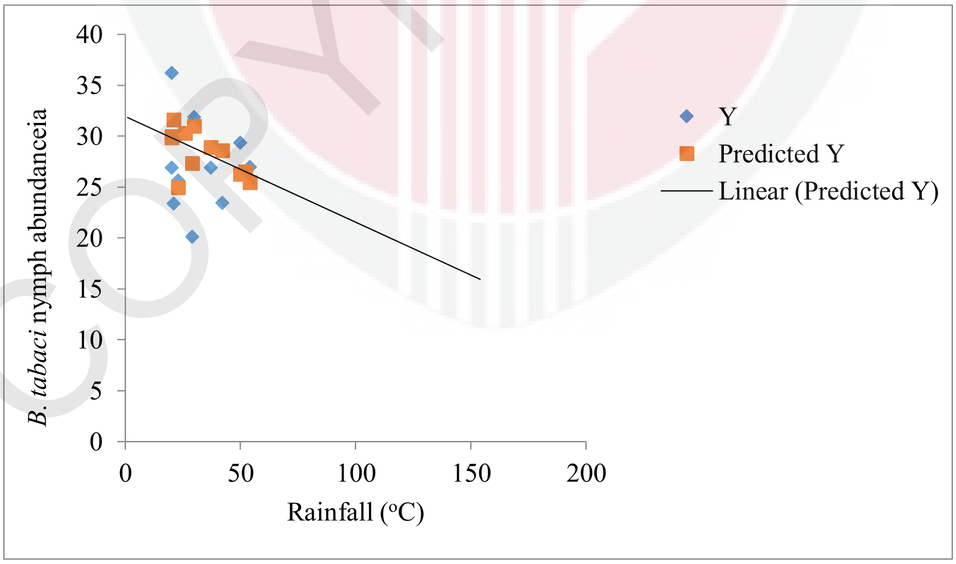
Appendix Figure D.30 : Relationship of Climatic Factors with *B. tabaci* Nymph Abundance on Tomato as Affected by Relative Humidity in the Dry Seasons of 2017 and 2018

$Y = -0.054x + 14.133$ ($R^2 = -0.574$)



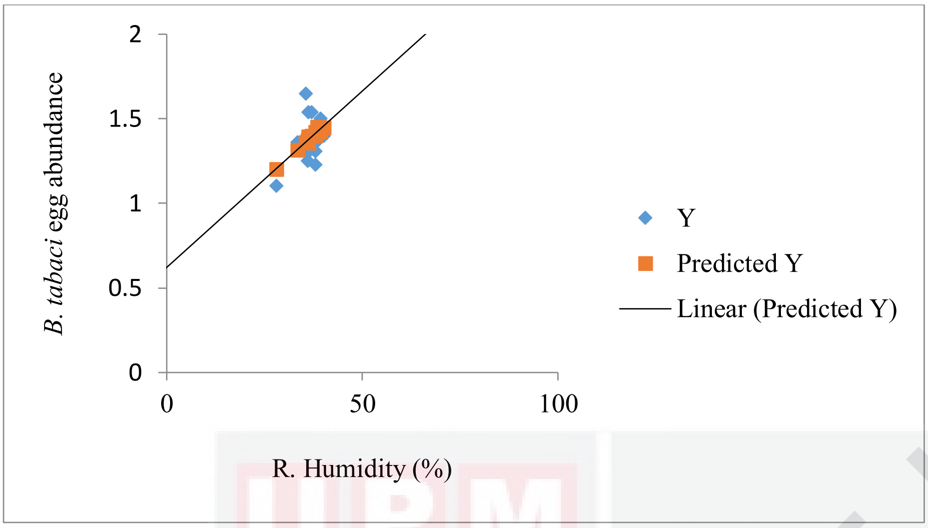
Appendix Figure D.31 : Relationship of Climatic Factors with *B. tabaci* Nymph Abundance on Tomato as Affected by Relative Humidity in the Rainy Seasons of 2017 and 2018

$Y = -0.541x + 33.872$ ($R^2 = -0.513$)



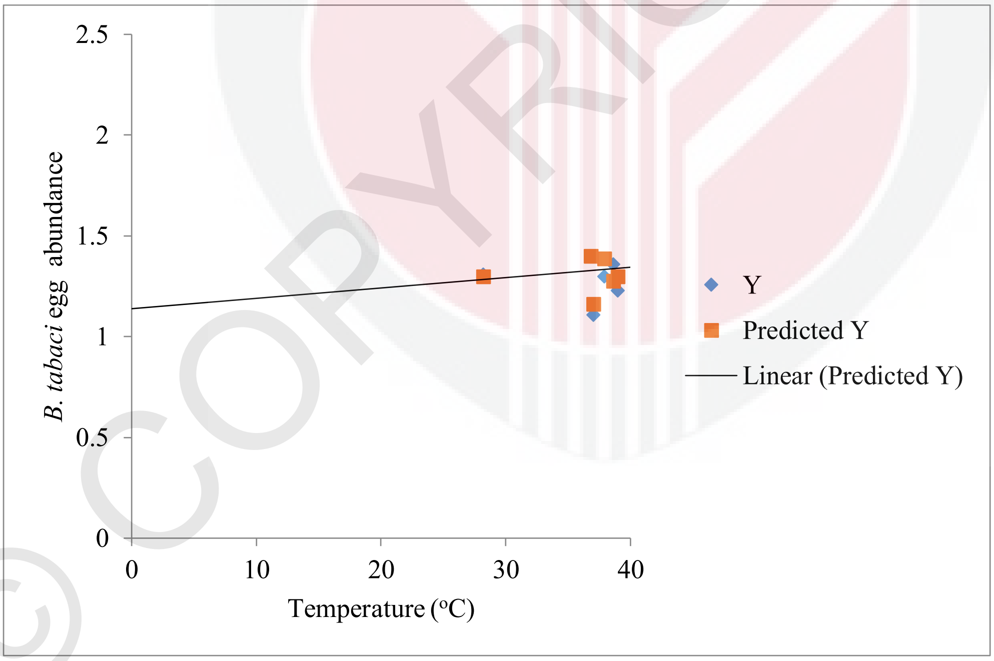
Appendix Figure D.32 : Relationship of Climatic Factors with *B. tabaci* Nymph Abundance on Tomato as Affected by Rainfall in the Rainy Seasons of 2017 and 2018

$Y = 0.025x + 0.632$ ($R^2 = 0.968$)



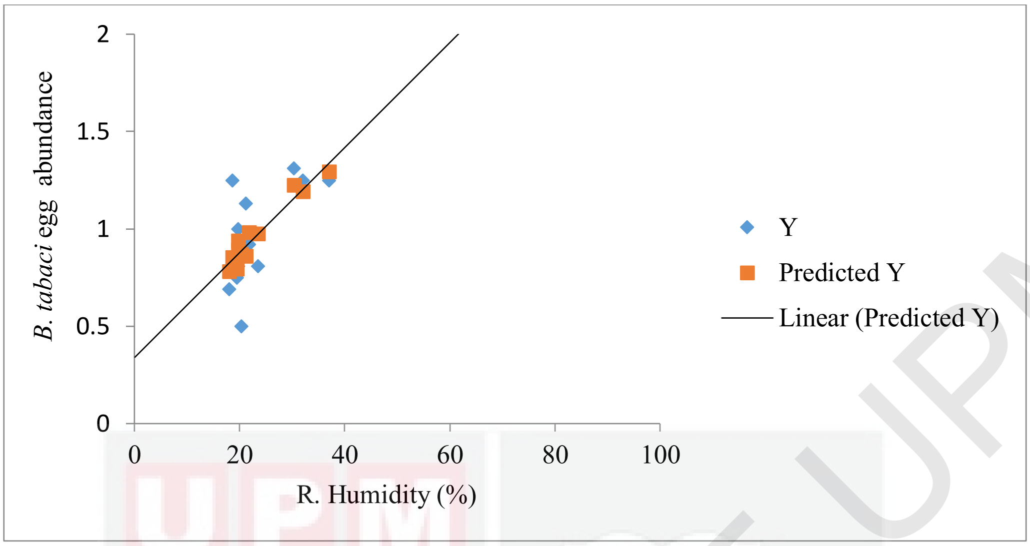
Appendix Figure D.33 : Relationship of Climatic Factors with *B. tabaci* Egg Abundance on Tomato as Affected by Temperature in the Dry Seasons of 2017 and 2018

$Y = 0.065x + 1.128$ ($R^2 = 0.447$)



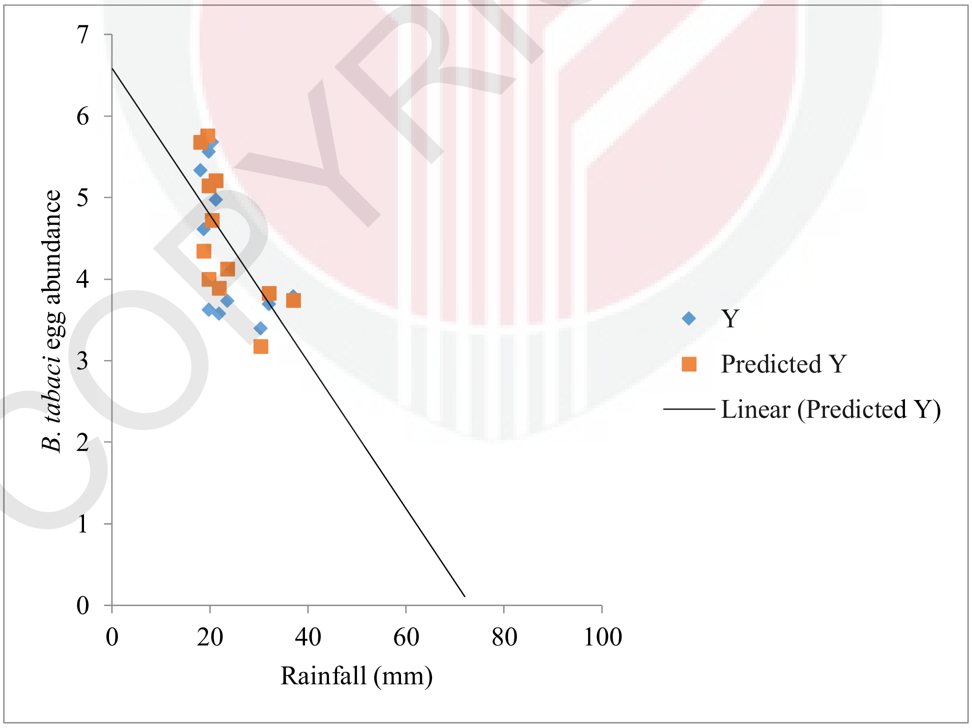
Appendix Figure D.34 : Relationship of Climatic Factors with *B. tabaci* Egg Abundance on Tomato as Affected by Temperature in the Rainy Seasons of 2017 and 2018

Y = 0.029x + 0.336 (R^2 = 0.936)



Appendix Figure D.35 : Relationship of Climatic Factors with *B. tabaci* Egg Abundance on Tomato as Affected by Relative Humidity in the Dry Seasons of 2017 and 2018

Y = - 096.x + 6.578 (R^2 = - 0.761)



Appendix Figure D.36 : Relationship of Climatic Factors with *B. tabaci* Egg Abundance on Tomato as Affected by Rainfall in the Rainy Seasons of 2017 and 2018

Appendix E

Appendix Table E1 : Mean Monthly Meteorological Data of the Experimental Site during 2017 and 2018 Trial Period

Month	Year	Total Rainfall (mm)	Average Temperature (0^{O} C)	Average Relative Humidity (%)
January	2017	0.0	32.8	27.0
February	2017	0.1	33.7	17.0
March	2017	10.0	34.0	13.0
April	2017	0.4	40.1	10.0
May	2017	129.0	32.3	32.9
June	2017	126.0	29.0	51.0
July	2017	322.8	26.5	78.3
August	2017	358.0	21.0	79.0
September	2017	82.4	28.3	87.2
October	2017	123.0	28.5	50.0
November	2017	0.0	30.5	27.1
December	2017	0.0	24.4	22.1
January	2018	1.0	31.7	23.0
February	2018	5.0	36.2	19.9
March	2018	27.0	39.5	26.1
April	2018	39.0	39.0	40.0
May	2018	79.0	36.0	53.8
June	2018	132.0	35.2	63.0
July	2018	179.0	32.0	72.0
August	2018	235.0	31.0	87.5
September	2018	160.0	28.0	83.9
October	2018	58.0	35.7	59.3
November	2018	0.00	27.6	37.1
December	2018	0.00	25.2	28.0

[Source: Meteorological Station, Department of Soil and Engineering Sciences, Faculty of Agriculture, Kebbi State University, Aliero, Kebbi State, Nigeria]

Appendix Plate I : The Net Covered Plots

Appendix Plate II : Tomato Plants Growing Inside the Insect Proof Nets

BIODATA OF STUDENT

The student Muhammad Kwaifa Nasiru was born in a Town called Gusau, Zamfara State, Nigeria on the 24th day of September, 1970. Obtained his First Primary School Living Certificate in 1983 at the Arkilla Primary School, Sokoto and Senior School Certificate in 1989 at Nagarta College Sokoto. He graduated with a Bachelor of Agriculture Degree from the Usmanu Danfodiyo University, Sokoto in 1999. Graduated with a Master of Philosophy Degree in Crop Science in the Usmanu Danfodiyo University, Sokoto. Futhermore, in February 2016, he registered for Doctor of Philosophy (PhD) programme in the field of Entomology in the Department of Plant Protection, Faculty of Agriculture, Universiti Putra, Malaysia. He is a member of the Asian Council of Science Editors (ASCE), Member of the Entomological Society of Nigeria (ESN), member of the International Society of Plant Protection (ISPP), member, LifeDNA number: 234.26973, Member, ORCID No.: 000-00033-4371-8026, member, Agricultural Society of Nigeria (ASN), member, Nigerian Society of Plant Protection, member Organic Agriculture Project in Tertiary Institutions in Nigeria (OAPTIN). Secretary, Fculty of Agriculture, Kebbi State University of Science and Technology, Aliero, Kebbi State, Journal and Seminar Committee (2024). Currently working with the Kebbi State University of Science and Technology, Aliero, Kebbi State, Nigeria (2008 to date). He is Happily married to Rabi'a Sa'idu and blessed with 7 children.

PUBLICATION

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