OCCURRENCE, DISTRIBUTION AND ALTERNATIVE HOSTS OF VIRUSES OF IRRIGATED TOMATO (*Solanum lycopersicum* L.) FIELDS IN SOKOTO AND ZAMFARA STATES, NIGERIA

BY

Ibrahim BELLO, B. AGRIC. (SOKOTO) 2010
P13AGCP8002

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OFA MASTER OF SCIENCE DEGREE IN CROP PROTECTION

DEPARTMENT OF CROP PROTECTION,
FACULTY OF AGRICULTURE,
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

JULY, 2017

DECLARATION

I declare that the work in this dissertation entitled "Occurrence, Distribution and Alternative Hosts of Virusesof Irrigated Tomato(*Solanum lycopersicum* L.)Fields in Sokoto and Zamfara States, Nigeria" was carried out by me in the Department of Crop Protection. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

IBRAHIM BELLO	_____	_____
Name of Student	Signature	Date

CERTIFICATION

This dissertation entitled "OCCURRENCE, DISTRIBUTION AND ALTERNATIVE HOSTS OF VIRUSES OF IRRIGATED TOMATO(*Solanum lycopersicum* L.)FIELDS IN SOKOTO AND ZAMFARA STATES, NIGERIA" by Ibrahim BELLO meets the regulations governing the award of the degree of Master of Science in Crop Protection of the Ahmadu Bello University, and is approved for its contribution to scientific knowledge and literary presentation.

Prof. M. D. Alegbejo Sign_____Date_____
(Chairman, Supervisory Committee)

Prof. O. O. Banwo Sign_____ Date_____
(Member, Supervisory Committee)

Prof. B. D. Kashina Sign_____ Date_____
(Member, Supervisory Committee)

Prof. O. O. Banwo Sign_____ Date_____
(HeadDepartment of Crop Protection)

Prof. S. Z. Abubakar Sign_____ Date_____
(DeanSchool of Postgraduate Studies)

ACKNOWLEDGEMENTS

All praise is due to Almighty Allah, Whose infinite mercy, made it possible for me to complete this work. May His peace and blessings be upon the Noble Prophet, Muhammad, his household, his companions and those that follow their footstep till the Day of reckoning.

My sincere appreciation goes to my mentor and the Chairman of my supervisory committee, Professor Matthew D. Alegbejo, for his tireless effort, constructive criticisms, guidance and patience that made this work a success. I would also like to express my profound gratitude to the distinguished Professors O. O. Banwo and B. D. Kashina for their immense contributions to this work. May God reward you abundantly.

My appreciation goes to the management of UDUS for granting me a Study Leave to embark on the program. I wish to thank Prof. A. U. Dikko (Dean, Faculty Agriculture) andDrU. Aliyu(Head Department of Crop Science) for facilitating my study period throughout the programme. Prof. N. D. Ibrahim of same Departmentfor guidance and counsellingand the entire staff of Faculty of Agriculture,UDUS for their prayers and supports during my study period.I am also greatly thankful to Dr J.Alhassan Department of Crop Science,Faculty of Agriculture, UDUS for the identification of weeds

I wish to thank Prof. O. O. Banwo (Head, Department of Crop Protection) andall my lecturers, Department of Crop Protection A. B. U. Zaria for contributinggreatly to my understanding of the Crop Protection profession. My heartfelt thank goes to Dr A. I. Shero Department of Agronomy, Faculty of Agriculture, ABU for the statistical assistance.I remain grateful to A. Zubairu, S. O. A. Jonathan, Mrs H. J. Wakawa, B. Muhammad, B. D. Abdulhadi and A. Kabir for technical and physical assistance that make this research possible. To members of Department of Crop Protection, friends and well-wishers, May Almighty Allah rewards all of you.

My greatest appreciation is extended to my parents, Mallam Bello Abubakar and Mallama Nana Bello for their prayers, encouragement and vision that have taken me to this level today. May Allah reward you with Jannatul Firdaus. To my wife,Mallama Hauwa'u Abubakar, and my children, Firdaus and Abubakar, I say thank you for your patience and care during the difficult study period. I am particularly grateful to my

elder brothers, Mallam Nashiru Bello and Mallam Abubakar Bello for their prayers and support.

ABSTRACT

Field surveys were conducted during the 2016 dry season in three Local Government Areas in Sokoto and Zamfara States of Nigeria to determine the occurrence, distribution and alternative hosts of viruses of tomato [*Solanum lycopersicum* (L.)]. A total of 18 tomato farms were surveyed in the two States, 9 in each of the States. Sampling was done in five 4×4 m^2 quadrants in the three selected fields per Local Government Area. Tomato plant with curl, mosaic, mottling, distortion, stunting, chlorosis and necrotic symptoms, as well as, asymptomatic plants were sampled. A total of ninety weed samples,forty five from each of the States were also collected during both dry and rainy seasons.The presence of tomato viruses was detected using the Double antibody sandwich enzyme linked immunosorbent assay (DAS-ELISA) for*Tomato aspermy virus* (TAV) and *Tomato mosaic virus* (ToMV) and the Triple antibody sandwich-enzyme linked immunosorbent assay (TAS-ELISA)for *Tomato leaf curl virus* (TYLCV).*Tomato aspermy virus, Tomato mosaic virus* and *Tomato yellow leaf curl* virus were detectedeither singly or in mixed infections in all the three Local Government Areas each of Sokoto (TAV 17 %, ToMV 19.3 %, TYLCV 3.7 %, TAV + ToMV 7.4 %, TAV + TYLCV 3.7 %, ToMV + TYLCV 8.9% and TAV + ToMV + TYLCV 2.2 %) and Zamfara (TAV 20 %, ToMV 17.8 %, TYLCV 11.9 %, TAV + ToMV 3.7 %, TAV + TYLCV 12.6 %, ToMV + TYLCV 5.2 % and TAV + ToMV + TYLCV 2.2 %) states respectively. In Sokoto State, one weed species (*Ludwigia decurrens*Walter.) from the family *Onagraceae*,was establishedas a host of *Tomato aspermy virus* (TAV). Twoweed species (*Thelepogon elegans* L. and*Pennisetum pedicellata* Trin)and one weed species (*Vigna ambasensis*Vigamb.) from the Poaceae and *Fabaceae*respectivelywere hosts of *Tomato mosaic virus* (ToMV). Three weed species (*Euphorbia hirta* L., *Physalis peruviana* L. and *Eclipta alba* L.) from three different families (*Euphorbiaceae,Solanaceaeand Asteraceae*respectively) were found to be hosts of*Tomato yellow leaf curl virus* (TYLCV). In Zamfara State, one weed species (*Phyllanthus amarus* Schum & Thonn.) from the family *Euphorbiaceae*identified as a host of *Tomato aspermy virus* (TAV). Two weed species (*Pennisetum pedicellata* Trin. and *Portulaca oleracea*L.) from the families (*Poaceae and Portulacaceae,* respectively) and one (*Euphorbia hirta* L.) from the family *Euphorbiaceae* were identifiedas ahosts of*Tomato mosaic virus* (ToMV) and *Tomato yellow leaf curl virus* (TYLCV) respectively.

TABLE OF CONTENTS

Content

Title Page ---------- I

Declaration---------- ii

Certification---------- iii

Acknowledgements---------- iv

Abstract---------- vi

Table of Contents---------- vii

List of Tables ---------- x

List of Figures---------- xi

List of Plates ---------- xii

List of Appendices ---------- xiii

List of Virus Abbreviations---------- xiv

1.0 INTRODUCTION ---------- 1

1.1 Justification of the Study---------- 4

1.2 Objectives of the Study---------- 5

2.0 LITERATURE REVIEW ---------- 6

2.1 The Tomato Plant---------- 6

2.1.1 Origin and distribution of tomato ---------- 6

2.1.2 Taxonomy and morphology of tomato ---------- 7

2.1.3 Botanical description of tomato plant---------- 7

2.1.3 Production of tomato ---------- 8

2.1.5 Cultivation of tomato ---------- 12

2.1.6 Nutritional composition tomato ---------- 14

2.1.7 Uses of tomato ---------- 17

2.2 Constraints to Tomato Production---------- **18**

2.2.1 Pests and diseases of tomato---------- 19

2.3 Viruses of Tomato ---------- **20**

2.4 Management of Tomato Viruses---------- **31**

2.5 Alternative hosts of viruses of Tomato---------- **32**

2.6 Diagnosis of Tomato Viruses---------- **36**

3.0 MATERIALS AND METHODS---------- **40**

3.1 Surveys for Tomato Viruses---------- **40**

3.2 Laboratory Detection of Viruses of Tomato---------- **44**

3.2.1 Double antibody sandwich Enzyme-Linked Immunosorbent Assay (DAS-ELISA) for *Tomato aspermy virus* and *Tomato mosaic virus* detection-------- 44

3.2.2 Triple antibody sandwich Enzyme-Linked Immunosorbent Assay (TAS-ELISA) for *Tomato yellow leaf curl* virus detection---------- 45

3.4 Data Analysis---------- **46**

4.0 RESULTS---------- **47**

4.1 Incidence of Tomato in Viruses in Sokoto and Zamfara---------- **47**

4.1.1 Incidence of tomato viruses in three Local Governments of Sokoto State--- 49

4.1.2 Incidence of tomato viruses in three Local Governments of Zamfara State- 51

4.1.3 Occurrence of viruses of tomato in Sokoto and Zamfara States---------- 53

4.1.4 Distribution of viruses of tomato in Sokoto and Zamfara States ---------- 55

4.2. Weed host of viruses of tomato in Sokoto and Zamfara States---------- 60

5.0 DISCUSSION---------- **67**

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION ---------- **73**

6.1 Summary---------- **73**

6.2 Conclusion---------- **73**

6.3 Recommendations---------- **74**

REFERENCES---------- **75**

APPENDICES---------- **90**

LIST OF TABLES

1: Major tomato producing countries in the world---------- 10

2: Tomato producing countries in Africa---------- 11

3: Major nutrients contained in tomato fruit---------- 16

4: Distribution of *Tomato aspermy virus*, *Tomato mosaic virus*, *Tomato yellow leaf curl virus* in three Local Government Areas of Sokoto State, 2016 dry season---------- 56

5: Distribution of *Tomato aspermy virus*, *Tomato mosaic virus*, *Tomato yellow leaf curl virus* in three Local Government Areas of Zamfara State, 2016 dry season---------- 57

6: Weed species tested against antisera of tomato viruses in Sokoto State, 2016 dry and rainy seasons---------- 61

7: Weed species tested against antisera of tomato viruses in Zamfara State, 2016 dry and rainy seasons---------- 64

LIST OF FIGURES

1: Local Government Areas in Sokoto State surveyed for viruses of tomato, 2016 dry season---------- 41

2: Local Government Areas in Zamfara State surveyed for viruses of tomato, 2016 dry season---------- 42

3: Incidence of tomato viruses in (a) Raba (b) Kware (c) Tureta Local Government Areas of Sokoto State, 2016 dry season---------- 50

4: Incidence of tomato viruses in (a) Tsafe (b) Talata Mafara (c) Bakura Local Government Area of Sokoto State, 2016 dry season---------- 52

5: Occurrence of viruses infecting tomato in(a) Sokoto (b) Zamfara State, 2016 dry season---------- 54

6**:**Distribution of TAV, ToMV and TYLCV in Sokoto State, 2016 dry season---- 58

7**:**Distribution of, TAV, ToMV and TYLCV in ZamfaraState, 2016 dry season-- 59

LIST OF PLATES

I:A = Necrotic symptomcaused by TAV (arrow); B = Yellowing symptom induced by ToMV (arrow);C = Leaf curl caused by TYLCV (arrow) on tomato plant ---------- 48

LIST OF APPENDICES

I: Sample of structured questionnaire administered to Tomato farmers in Local Government Areas Sokoto and Zamfara States, 2016 dry Season ---------- 91

II: Compositions of buffers used---------- 93

III: Geographic and Disease Datain Sokoto State, 2016 dry season---------- 94

VI:Agronomic Data at Tomato Farms in Sokoto State,2016 dry season---------- 95

V: Geographic and Disease Datain Zamfara State, 2016 dry season---------- 96

VI: Agronomic Data at Tomato Farms in Zamfara State, 2016 dry season---------- 97

LIST OF VIRUS ABBREVIATIONS

Abbreviation Word in full

1. CMV*Cucumber mosaic virus*
2. PVMV*Pepper veinal mottle virus*
3. PV X *Potato virus X*
4. PVY*Potato virus Y*
5. TAV *Tomato aspermy virus*
6. TBTV*Tomato bunchy top virus*
7. TLCV*Tomato leaf curl virus*
8. TMV*Tobacco mosaic virus*
9. ToMV*Tomato mosaic virus*
10. TSWV*Tomato spotted wilt virus*
11. TYLCV *Tomato yellow leaf curl virus*

CHAPTER ONE

1.0 INTRODUCTION

Tomato (*Solanum lycopersicum* L.*)*, belongs to the family Solanaceae which contains more than 3,000 species, including plants of economic importance such as potatoes, eggplants, tobacco, petunias and peppers (Bai and Lindhout, 2007). It is believed to have its origin in South America (Naika *et al.,* 2005) but cultivated and consumed worldwide. China leads world production with about 50 million tonnes followed by India with 17.5 million tonnes (FAOSTAT, 2014). Nigeria is also ranked second largest producer in Africa and fourteenth largest in the world, producing 1.56 million tonnes annually at an average of 27.5 tonnes per hectare (FAOSTAT, 2014). It is one of the most important vegetables grown for it edible fruits. Tomato is cultivated in Nigeria on an annual total area of one million hectares. It makes up about 18 per cent of the average daily consumption of vegetables in Nigerian homes (Chidi, 2012). In Nigeria, production spreads all over the country, however, the major producing areas lie between latitudes 7.5 °N and 13 °N, and within a temperature range of 25 – 34 °C (Villareal, 1980). The areas include most States in northern Nigeria such as Bauchi, Benue, Borno, Gombe, Kaduna, Kano, Kwara, Plateau, Sokoto, Zamfara and the south western States such as Oyo, Osun, Ogun, Ekiti and Ondo (Denton and Swarup, 1983; Olaniyi *et al.*, 2010; Adekiya *et al*., 2009).

In the tropics, tomato grows well on most mineral soils that have proper water holding capacity and aeration, and are free of salts. It prefers deep, well drained sandy loam soils. The upper layer needs to be permeable. Soil depth of 15 to 20 cm is needed to grow a healthy crop. In heavy clay soils, deep ploughing allows better root

penetration. Tomato is moderately tolerant to a wide range of pH (level of acidity), but grows well in soils with a pH of 5.5 – 6.8 with adequate nutrient supply and availability (Shankara *et al*., 2005). Addition of organic matter is generally favourable for good growth. Soils with very high organic matter content, like peat soils, are less suitable due to their high water holding capacity and nutrient deficiencies (Shankara *et al*., 2005). Although the plant is perennial, it is grown as annual. The size, shape, colour, flavour, vitamin content, method of growth (which may be erect or sprawling) and resistance to disease vary according to the variety (Villareal, 1992). It is a branching, herbaceous plant with hairy weak trailing stems.

Tomato is consumed fresh or as processed products such as canned tomato, sauce, juice, ketchup, stews and soup (Lenucci *et al.*, 2006). It is consumed principally due to its high concentrations of vitamins A, B and C, and fair concentrations of protein, calcium and niacin (Norman, 1992; Bodunde, 2003; Kaushik *et al.,* 2011). It has medicinal values and used for blood purification and cure of digestive ailments (Kaushik *et al.,* 2011). Studies have shown that consumption of raw tomato and tomato based products is associated with a reduced risk of cancer and cardiovascular diseases (Clinton, 1998; Giovannucci *et al*., 2002). This protective effect has been mainly attributed to its valuable bioactive components with antioxidant properties (Borguini and Torres, 2009). It is also a major source of antioxidants contributing to the daily intake of a significant amount of these molecules. Tomato antioxidants include carotenoids such as β-carotene, a precursor of vitamin A and mainly lycopene, which is largely responsible for the red colour of the fruit, vitamins such as ascorbic acid and tocopherols, and phenolic compounds such as flavonoids and hydroxycinnamic acid derivatives (Clinton, 1998; Borguini and Torres, 2009).

Due to its various uses, both for processing and fresh market has become one of the most important crops in agriculture for smallholder farmers (Anang *et al*., 2013). However,the yield in West Africa particularly Nigeria is not encouraging, especially when compared to developed countries. For instance, tomato production in Nigeria was estimated to be 1.56 million tonnes in 2012, while the United States of America estimate for the same year was 13.20 million tonnes (FAOSTAT, 2014). Yield per hectare in Nigeria was estimated at 1/7th of that of the U.S.A (FAO, 2010). Many factors have been reported to be responsible for this poor yield performance (Sangoyomi *et al*., 2011). The production of this vegetablefaced with a lot of constraints of abiotic (excessive heat, blossom end rot, fruit cracking, catfaced fruit, sunscald, blotchy fruit, physiological leafroll, herbicide injury etc.) and biotic (insects, mites, nematodes, fungi, bacteria, and viruses etc.) factors (Marjan *et al*., 2000; Srinivasan, 2010; Osei *et al*., 2012).

Tomato fields in Nigeria are known to be constantly plagued by virus diseases. While, some are prominent in the wet season others are prominent in the dry season under irrigation. The availability of the source of virus, susceptible host and presence of vectors determine the occurrence and the severity of disease. The most common and important virus diseases of tomatoes in Nigeria include: *Tomato leaf curl virus* (TLCV), *Tomato yellow leaf curl virus* (TYLCV), *Tomato mosaic virus*, (ToMV), *Tomato bunchy top virus* (TBTV), *Pepper veinal mottle virus* (PVMV), *Cucumber mosaic virus* (CMV), *Tobacco mosaic virus* (TMV) and *Potato virus y* (PVY) (Simons and Sobulo, 1975; Alegbejo, 2015). These viruses have been reported to cause serious yield losses on tomato annually. Known hosts can be cultivated vegetables, ornamentals, wild or weed plant species (Jane *et al*., 2007). These viruses are spread

mainly by whitefly *(Bemisia tabaci* Genn) or aphids (*Myzus persicae*) and grafting (Butter and Rataul, 1977; Sanchez *et al*., 2000). The whitefly has large number of hosts upon which it can feed and reproduce. Reservoirs of the vector may also vary among production regions (Jane *et al.*, 2007).

Symptoms induced by viruses of tomato vary depending on the growth stage at the time of initial infection, environmental conditions and cultivars/variety of tomato plants. These include marginal leaf yellowing/chlorosis of leaf margin of the newest leaves, interveinal chlorosis, upward curling, reduction in leaf size, puckering, shortening of internodes resulting in dwarf bushy appearance, excessive branching and stunting of the plants (Cohen and Antignus, 1994). Recommended management strategies include use of resistant varieties, virus-free transplants, management of vectors,manipulation of sowing date, intercropping, sanitation of tomato field and elimination of virus reservoir (Kashina *et al*., 2002a; Sastry and Zitter, 2014).

1.1 Justification of the Study

Tomato is the world's major vegetable crop and known as protective food because of its special nutritive value (Rukhsar*etal.*, 2015). It is also the most popular vegetable crop in Nigeria dominating the largest area under production among vegetable crops (Ramalan, 1994).The popularity of tomato as fresh and processed food has made it an important source of vitamin A, B and C in diets. It is consumed throughout the world on a large scale and serves many benefits for heart and other organs and contains carotene and lycopene, one of the most powerful natural antioxidants (Mourvaki *et al*., 2005).

Despite its numerous uses, yield obtained per hectare is very low in Sokotoand Zamfara states. SADP (2008) reported highest yield of tomato in Sokoto to be 8 tonnes/ ha compared to average yield of 27.5 tonnes/ ha in Nigeria and 192 tonnes/ ha in United States (FAOSTAT, 2014).Viruses have been reported to be one of the most limiting factors in tomato production in the northern states of Nigeria (Alegbejo, 1995).TLCV was reported to have caused yield loss of over 23 % in northern states of Nigeria (Alegbejo and Ogunlana, 1995) whileEraslan *et al*. (2007) reported *Tomato mosaic virus* to reduce tomato yield by up to 25 %. A combination of TYLCV and ToMV cause as much as 20-90 % yield loss in West Africa (Lana and Adegbola, 1977). Tomato viruses have one of the widest reported host ranges for viruses, infecting more than 30 species in over 12 plant families (Jane *et al*., 2007), which harbour the viruses during both wet and dry seasons.

There was no any record of survey to identify tomato viruses in the study areasdespite the great threats they pose on the crop yield's potential prior to this work. The weed hosts, which serve as reservoir for the viruses and their vectors, need to also be identified (Narayana *et al*., 2002) for effective management of the virus diseases. Therefore, this study was conducted to identify the occurrence, distribution and alternative hosts of the viruses of tomato in Sokoto and Zamfara States of Nigeria.

1.2 Objectives of the Study

The objectives were to identify:

1. The occurrence and distribution of viruses of irrigated tomatoin Sokoto and Zamfara States, Nigeria.

2. The alternative hosts of the viruses.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Tomato Plant

2.1.1 Origin and distribution of tomato

The present day Tomato (*Solanum lycopersicum* L.*)* has a very short history of human consumption (Tan *et al.,* 2010). It was believed to have its origin in the South American Andes (Naika *et al.,* 2005) which is in present day Peru where it was growing in wild at the foot of hills. It was then taken to other parts of the world by early explorers where it was planted as ornamental curiosities but not eaten. In Europe for instance it was planted in gardens as decorative plants and was considered poisonous. Although tomato was accepted later as an edible crop in Europe in about 1840 (Paran and van der Knaap, 2007) there was still strict opposition to its consumption in other parts of the world. Global tomato production increased during the 1920s as a result of breakthroughs in technologies that made mechanised processing possible (Tan *et al.,* 2010). Itis one of the most popular and widely grown fruits in the world including Africa (Osemwegi *et al*., 2010).

In Nigeria, production spreads all over the country, however, the major producing areas lie between latitudes 7.5 °N and 13 °N, and within a temperature range of 25–34 °C (Villareal, 1980). The areas comprises most States in northern Nigeria such as Bauchi, Benue, Borno, Gombe, Kaduna, Kano, Kwara, Plateau, Sokoto, Zamfara and the south western States:Oyo, Osun, Ogun, Ekiti and Ondo (Denton and Swarup, 1983; Olaniyi *et al.*, 2010; Adekiya *et al*., 2009).

2.1.2 Taxonomy and morphology of tomato

S. lycopersicum with approximately 1,500 species (Knapp, 2006), represents one of the largest genera of the angiosperms and is the largest genus in the Solanaceae.The genus is widespread, but circum-Amazonian tropical South America is the center of diversification and species richness (Knapp, 2002).In the most recent traditional classification of the entire genus based on overall morphology, D'Arcy (1972) distinguished seven subgenera and 52 sections. *Solanum* includes valuable crops, such as tomato (*S. lycopersicum* L.), eggplant (*S. melongena* L.), potato (*S.tuberosum* L.), other edible species like pepino (*S. muricatum* Ait.), naranjilla (*S. quitoense* Lam.), cocona (*S. sessiliflorum* Dunal), and species used for medicinal or ornamental purposes.

From botanical point of view, the tomato is a berry fruit. Nevertheless, it contains a much lower sugar content compared to other fruits. It is a diploid plant with 2n = 24 chromosomes. Tomato belongs to the Solanaceae family, which contains more than 3,000 species, including plants of economic importance such as potatoes, eggplants, tobacco, petunias and peppers (Bai and Lindhout, 2007). In 1753, Linnaeus placed the tomato in the Solanum genus (alongside with potato) under the specific name *S. lycopersicum*. In 1754, Philip Miller moved it to its own genus, naming it *Lycopersicum esculentum* (Foolad, 2007; Perlata and Spooner, 2007).

2.1.3 Botanical description of tomato plant

It has a vigorous tap root system that grows to a depth of 50 cm or more.The main root produces dense lateral and adventitious roots. Stem growth habit ranges between erect and prostrate. It grows to aheight of 2-4 m. The stem is solid, coarse, hairy and

glandular. Leaves are spirally arranged, 15-50 cm long and 10-30 cm wide. Leaflets areovate to oblong, covered with glandular hairs. Small pinnate appearsbetween larger leaflets. Inflorescence is clustered and produces6-12 flowers. Petiole is 3-6 cm. Flower is bisexual, regular and 1.5-2 cm in diameter. They grow opposite orbetween leaves. Calyx tube is short and hairy, sepals are persistent.Usually 6 petals up to 1 cm in length yellow and reflexedwhen mature. 6 stamens, anthers are bright yellow in colour surroundingthe style with an elongated sterile tip. Ovary is superiorand with 2-9 compartments. The crop is mostly self- but partly also cross-pollinated.Bees and bumble bees are the most important pollinators.Fruit is fleshy berry, globular to oblate in shape and 2-15 cm in diameter.The immature fruit is green and hairy. Ripe fruits range from yellow,orange to red. It is usually round, smooth or furrowed. Seeds: Numerous, kidney or pear shaped. They are hairy, light brown 3-5 mm long and 2-4 mm wide. The embryo is coiled up in the endosperm.Approximate weight of 1000 seeds is 2.5–3.5 g (Naika *et al.,* 2005).

2.1.4 Production of tomato

World tomato production in 2012 was about 161.8 million tonnes of fresh fruit from an estimated 3.9 million ha (Table 1). China leads world tomato production with about 50 million tonnes followed by India with 17.5 million tonnes (FAOSTAT, 2014).Tomato is an important and popular grown horticultural commodity in the world and ranks third in global production of all horticultural produce only behind Irish potatoes and sweet potatoes (Tan *et al.,* 2010). In Africa, the total production for 2012 was 17.938 million tonnes with Egypt leading the continent with 8.625 million tonnes (Table 2). Nigeria dominated the largest area under production of vegetable crops (Ramalan, 1994).Nigeria also ranked second largest producer of tomato in Africa and

fourteenth largest in the world, producing 1.56 million tonnes annually at an average of 27.5 tonnes per hectare (FAOSTAT, 2014). Increase in demand of the commodity resulted in increased production in both upland and low land areas. Its production in the savannah zone of Nigeria is mainly during the dry season when it has to be fully supported by irrigation (Anon, 2000). It is the most widely grown vegetable crop under irrigation but lack of water is limiting the production and expansion (Ramalan, 1994).

TABLE 1: Major tomato producing countries in the world

Rank	Country	Production (tonnes/annum)
1	China	50,000,000
2	India	17,500,000
3	USA	13,206,950
4	Turkey	11,350,000
5	Egypt	8,625,219
6	Iran	6,000,000
7	Italy	5,131,977
8	Spain	4,007,000
9	Brazil	3,873,985
10	Mexico	3,433,567
11	Uzbekistan	2,650,000
12	Russia	2,456,100
13	Ukraine	2,274,100
14	Nigeria	1,560,000
15	Portugal	1,392,700

Source: FAOSTAT (2014).

TABLE 2: Tomato producing countries in the Africa

Rank	Country	Production (tonnes/annum)
1	Egypt	8,625,219
2	Nigeria	1,560,000
3	Morocco	1,219,071
4	Tunisia	1,100,000
5	Cameroon	880,000
6	Algeria	796,963
7	South Africa	64,740
8	Sudan	529,200
9	Kenya	397,000
10	Ghana	321,000
11	Tanzania	255,000
12	Mozambique	250,000
13	Benin	244,742
14	Libya	225,000
15	Niger	188,767

Source: FAOSTAT (2014).

2.1.5 Cultivation of tomato

Tomato is one of the most popular, versatile, and widely grown vegetable throughout the world and in nearly every home garden. It was first grown in Europe for ornamental purpose. Its cultivation for food crop was established along with its dispersion throughout Europe and other areas. The crop was cultivated for the first time in North America in the early 1700s (Kolawole *et al.,* 2010).

Tomato requires a relatively cool, dry climate for high yield and premium quality. However, it is adapted to a wide range of climatic conditions from temperate to hot and humid tropical. The optimum temperature for most varieties lies between 25 and 34 °C. The plants can survive a range of temperatures, but the plant tissues are damaged below 10 °C and above 38 °C (Naika *et al.,* 2005). The soils in the Nigeria are generally low in fertility and enhanced crop yield is only possible through external use of organic and inorganic fertilizer (Quinn, 1980).Tomato grows well on most mineral soils that have proper water holding capacity and aeration, and are free of salt. It prefers deep, well drained, sandy loam soils. The upper layer needs to be permeable. Soil depth of 15 to 20 cm is needed to grow a healthy crop. In heavy clay soils, deep ploughing allows better root penetration. Tomato is moderately tolerant to a wide range of pH (level of acidity), but grows well in soils with a pH of 5.5 – 6.8 with adequate nutrient supply and availability. Addition of organic matter is, in general, favourable for good growth. Soils with very high organic matter content, like peat soils, are less suitable due to their high water holding capacity and nutrient deficiencies (Naika *et al.,* 2005).

Tomato is normally transplanted because much better results are gained when seedlings are raised in a nursery. Two methods of raising seedling in nurseries can be used: sowing in seedbed and sowing in seedling tray (used by many farmers in Southeast Asia). The seedlings can be selected for growth and health before planting in the field. The plantlets can be well protected and the planting distance is more regular than after sowing directly in the field (Naika *et al.*, 2005).

Mulching is used principally as moisture conservation practice which not only reduces the number of irrigations required but has other benefits like increasing the root zone temperature and improving the nutrient uptake. Performance of tomato under mulch is dependent on mulching material (Hunter *etal*., 1991; Teasdale and Abdul-Baki, 1995; Amans *et al*., 2008).Staking is a means of providing supports to ensure clean and unblemished fruits which kept fruits off from the ground, minimizing diseases and rotting of fruits thereby increasing marketable yield (Hanna and Adams, 1982).

The physiological maturity of the fruit at harvesting stage has a major effect on quality (Beckles, 2012). Care must therefore be taken as to when to harvest the fruit for it to attain the best quality. Post-harvest physiologists describe three stages in the life span of fruits and vegetables: maturation, ripening and senescence. The maturation is indicative of the fruit being ready for harvest (FAO, 2008) and there are three maturity states at which tomatoes can be harvested. It can be harvested either in matured green, partially ripened state. Tomato being a climacteric fruit can be harvested at the matured green state allowing ripening and senescence to occur during the postharvest period of the fruit.

According to Moneruzzaman *et al.* (2009) and Orzolek *et al*. (2006), farmers targeting distant markets must harvest their tomatoes in a matured green state. This will not only give the producers ample time to prepare the fruit for the market but also prevent mechanical injuries during harvesting. Meanwhile, farmers in most African countries harvest tomatoes when they are partially or fully ripened. Fully ripened tomato is susceptible to injuries during harvesting resulting in shorter shelf life (Reid, 2002; Watkins, 2006; Toivonen, 2007). This may be the reason why there is high level of losses at full maturity stage in Africa.

2.1.6 Nutritional composition of tomato

Fruit quality has been assessed by the content of chemical compounds such as dry matter, Brix degree, acidity, single sugars, citric and other organic acids and volatile compounds (Thybo *et al*., 2006). A series of quantitative and qualitative changes of the chemical composition take place during fruit ripening. Organic acids, soluble sugars, amino acids, pigments and over 400 aroma compounds contribute to the taste, flavour and aroma volatile profiles of the fruit (Petro- Turza, 1987). Ripening is characterized by the softening, degradation of chlorophylls and increase in respiration rate, ethylene production and synthesis of acids, sugars and lycopene (Cano *et al*., 2003). The fruit contains higher levels of fructose and glucose than sucrose (Garvey and Hewitt, 1991).

Tomato has become an important cash and industrial crop in many parts of the world (Ayandiji *et al.*, 2011) not only because of its economic importance but also its nutritional value to human diet and subsequent importance in human health (Willcox *et al.*, 2003). Tomato is rich in vitamins, minerals, sugars, essential amino acids, iron,

dietary fibers and it therefore serves as source of these nutrients when consumed (Ayandiji *et al.*, 2011). Table 3 gives 15 main nutrients and their benefits derived from consuming a 123-gram of ripened tomato.

TABLE 3: Major nutrients contained in tomato fruit

Nutrients	Amounts (mg)
Calcium	1.2
Carbohydrate	4700
Copper	0.073
Dietary fiber	1500
Fat	200
Iron	0.33
Magnesium	1.4
Niacin	0.731
Pantothenic acid	0.109
Phosphorus	3
Potassium	292
Protein	1000
Thiamin	46
Total sugars	3200
Vitamin C	16.9

Source: The USDA National Nutrient Database (2010).

2.1.7 Uses of tomato

Tomato provides good nutritional balance to farm families as well as boosts their income and hence standard of living. Tomato can be used for a variety of recipes. It can be consumed fresh in salads, cooked in other dishes or processed into other food products (Grandillo *etal.,* 1999; Babalola *et al*., 2010 Ayandiji *et al.,* 2011; Ahmed *et al.,* 2012).

A few common recipes include tomato-watermelon sorbet, fried green tomato with bread and butter pickle, grilled chicken-tomato salad, tomato stew, tomato-chili soup and tomato-egg sandwich.

Tomato contains higher amounts of lycopene, a type of carotenoid with anti-oxidant properties (Arab and Steck, 2000) which is beneficial in reducing the incidence of some chronic diseases (Basu and Imrhan, 2007) like cancer and many other cardiovascular disorders (Freeman and Reimers, 2010). This anti-oxidant property and its health benefit have raised the interest in research and its consumption as a crop with medicinal importance (Di Mascio *et al.,* 1989). Lycopene is believed to be the main contributing compound responsible for lower risk of prostate cancer (Pohar *et al*., 2003). Other studies have also shown that consumption tomato-base foods can be linked to reduced incidence of a variety of cancers which include pancreatic, lung, stomach, colorectal, oral, bladder, breast and cervical cancers (Giovannucci, 2002). Lycopene in tomato enhanced fertility by improving the quality and swimming speed of sperm whilst reducing the number of abnormal sperm in men (Innes, 2014). Consumption of tomato can prevent old-age related diseases like dementia, osteoporosis, Parkinson's and Alzheimer's (Freeman and Reimers, 2010). Tomato has high sources of vitamin C and vitamin A which are vital in warding off muscular

degeneration and improve eyesight. It is also believed to be powerful blood purifier and clear up urinary tract infections. Its high fibre aids for easy digestion and weight loss. These numerous health benefits of tomato and tomato-based foods may be linked to its high production globally.

2.2 Constraints to Tomato Production

Tomato has the tendency of improving the lives of small scale rural farmers in most developing countries of the world. Besides the health benefits derived from tomatoes and tomato-based foods, the crop can serve as a source of income for farmers as a result of its numerous uses. The industry can increase the foreign exports earning of many African countries thereby contributing to Gross Domestic Products (GDP). In Ghana for instance, it has been identified as an area that has the ability for poverty reduction because of its potential for growth and employment creation (Anang *et al*., 2013) whilst in Nigeria, the production of the crop has improved the livelihood of most rural and peri-urban farmers (Adenuga *et al.,* 2013). Although, it can improve the livelihoods of rural farmers, studies have shown that the full potential of the crop has been under exploited because of many challenges. For instance most tomato farming in Nigeria is ranfed (Adenuga *et al.,* 2013) because of the lack of effective irrigation systems. Incidence of pests and diseases leading to low quality and quantity of tomato produced are also some constraints hampering the production of tomatoes in Africa.

Abiotic stresses such as those imposed by excess salts,reduced water supply leading to drought stress, excesswater leading to submergence and anoxia stress, sub-optimal ambient temperature leading to low temperaturestress, supra-optimal ambient temperature leading to hightemperature stress, oxidative stress caused by

differentabiotic stresses in conjunction with high light intensity,heavy metal stress and air pollutants stress negativelyaffect processes associated with biomass production andyield of tomato (Maiti *et al*., 2008).

2.2.1 Pests and diseases of tomato

Tomato is attacked by a wide variety of pests and diseases. Several kind of insects and mites attack tomato leaves, flower buds and fruit during its cultivation. The most commonly occurring pests are fruit worm or fruit borer (*Helicoverpa armigera* Hubner), army worm (*Spodopteralitura* Fabricius), beet army worm (*Spodotera axigua* Hubner), whitefly (*Bemisia tabaci* Genn.), leaf miner (*Tuta absoluta*) and two spotted spider mites (*Tetranychus urticae* Koch). However, whitefly and fruit worm are the major insect pests in most of the tropical regions of the world as whitefly transmits leaf curl virus diseases and fruit worm causes severe fruit damage, reducing the marketable yield (Srinivasan, 2010). Other insects that destroy the plants are flea beetle (*Epitrix hirtipennis* F. E.), aphids (*Myzus persicae* Sulzer), fruit flies (*Daccus* sp.), cutworms (*Peridroma saucia* Hubner) and hornworms (*Manduca quinquemaculata* Haworth) (Wittwer, 1998).Its cultivation is generally more restricted by diseases than pests in most locations. In recent years, there has been a great increase in smallholder tomato cultivation in Nigeria and other African countries both as food and as cash crops. In some countries after a few good years, the crop fails drastically seemingly due to a joint disease/nematode complex (Hill and Waller, 1990).

The major fungal diseases include leaf mould, fusarium wilt, target spot or early blight and leaf spots. Some of these diseases are soil-borne (Villarreal, 1992).*Septoria*leaf spot affects plants at any stage of development (Ohlendorf *et al.,* 2004). Another

important fungal disease is powdery mildew caused by *Oidium lycopersicum* Link (LaMondia, 1999). It is very important to scout for disease and to rogue infected plants as soon as they are detected (Douglas, 2005).

Cultivated fields in Nigeria are known to be constantly plagued by virus diseases. While some are prominent in the wet season others are prominent in the dry season under irrigation. Source of virus, susceptible host and presence of vectors determine the occurrence and the severity of disease. Most common and important virus diseases in Nigeria include *Tomato mosaic virus* (ToMV), *Tomato bunchy top virus* (TBTV), *Pepper veinal mottle virus* (PVMV), *Cucumber mosaic virus* (CMV), *Tobacco mosaic virus* (TMV), *Potato virus Y* (PVY), and *Tomato yellows* (Simons and Sobulo, 1975; Alegbejo, 2015).

2.3 Viruses of Tomato

About 146 viruses belonging to 33 genera infect tomato worldwide (Green, 1991) but only 15 genera are of economic importance. These are *Alfalfamovirus, Begomovirus,Carlavirus, Crinivirus, Cucumovirus, Ilarvirus, Luteovirus, Nepovirus, Potexvirus,Potyvirus, Tobamovirus, Tombusvirus, Topocuvirus, Tospovirus,* and *Tymovirus*. These fifteen genera belong to families *Bromoviridae,Bunyaviridae, Closteroviridae, Flexiviridae*, *Geminiviridae, Luteoviridae* and *Potyviridae* (Pringle, 1999). Family *Bunyaviridae* has only one assigned plant-infecting genus (*Tospovirus*) to which *Tomato spotted wilt virus* (TSWV) belongs. Nono-Womdim *et al.* (1994) reported that major tomato viruses in tropical Africa fell into five genera viz: *Tobamovirus, Cucumovirus, Tospovirus, Begomovirus*, and *Potyvirus*. No virus belonging to the genera *Alfamovirus, Potexvirus,* or *Closterovirus,* which have been

reported to occur on tomato in Europe (Fauquet and Mayo, 1999: Wisler, 1998; Green, 1991; Brunt *et al*., 1990). Family *Flexiviridae* has been recently approved by ICTV (Mayo and Brunt, 2005). Its major tomato virus is *Potatovirus X*, which belongs to genus *Potexvirus*. The most commonly encountered viruses were found to be *Tobacco mosaic virus* (TMV), *Tomato spotted wilt virus* (TSWV), *Tomato mosaic virus* (ToMV), *Tomato leaf curl virus* (TLCV), *Potato virus Y* (PVY) and *Cucumber mosaic virus* (CMV) (are the most widespread) (Alegbejo, 2015). Sastry (1982) was reported to have isolated *Pepper veinal mottle virus* (PVMV) in tomato. Among all the viruses of tomato, *Tomato leaf curl virus* (TLCV) Genus *Begomovirus* is the most devastating and economically significant pathogen of cultivated tomatoes in tropical and sub-tropical regions. Tomato mosaic and *Tomato leaf curl virus* diseases are the most serious diseases in West Africa as they cause as much as 20 - 90 % loss in fruit yields (Lana and Adegbola, 1977).

2.3.1 *Tomato leaf curl virus* (TLCV)

TLCVis a very devastating and economically significant pathogen of cultivated tomatoes in tropical and sub-tropical regions (Brown, 1994; Brunt *et al*., 1996; Nono-Womdim *et al*., 1996). Virions consist of a capsid that is not enveloped but elongated and exhibits icosahedralsymmetry. The capsid is geminate and genome is not segmented and contains a single molecule of circular, ambisense, single-strandedDNA. The virus has long been known in the Middle East, North, Central, East and West Africa, South East Asia, and Southern Europe (Alegbejo, 1995; Ladipot *et al.,* 2001). It has also been reported in the Caribbean region (Nakhla *et al*., 1994), Mexico (Momol *et al*., 1999; Valverde *et al*., 2001). It is the most limiting factor in tomato production between January and May in the northern states of Nigeria

(Alegbejo, 1995; Alegbejo and Ogunlana, 1995).According to Padidam *et al.* (1995), there are three distinct TLCVs based on nucleotide sequence comparisons. It is also considered that viruses of the genus *Begomovirus,* which have nucleotide sequence similarity levels below 90 % are considered distinct from each other (Padidam *et al*., 1995), although ICTV reported that this can only be concluded when complete genome sequences have been compared (Fauquet *et al*., 2003), and not on the basis of the intergenic region (IR) or coat protein gene alone.

Serological tests have played a big role in identifying tomato leaf curl viruses. They are widely used, but have limitations because of the need to obtain sufficient purified coat protein for the production of antisera (Chiemsombat *et al.*, 1991). Initially, polyclonal antibodies were used until Harrison *et al*. (1991) and others begun using monoclonal antibodies. They found that the advantage of using monoclonal antibodies is such that (1) though different viruses share some epitopes, there are those that are specific to one particular virus and (2) geminiviruses from the same geographic areas tend to share more epitopes than viruses from different regions. This, therefore, served as a basis for use of monoclonal antibodies to study relationships among geminiviruses using monoclonal antibody raised against *African cassava mosaic virus* (ACMV) (Macintosh *et al.*, 1992).

TLCV is distributed all over the world and transmitted through grafting and persistently by a whitefly (*Bemisia tabaci* Gennadius) of the Family *Aleyrodidae* (Gerling and Mayer, 1995; Alegbejo, 2015). High temperature that favours whitefly multiplication, weed hosts of the virus and crop, could lead to the development of an explosive epidemic if the crop is very susceptible type. Furrow or drip irrigation rather

than overhead irrigation could also enhance whitefly activities. Yield loss of over 50 % is common at Samaru, Zaria while in Katsina, Sokoto, and Borno states etc. 100 % infection and over 85 % yield loss or complete crop abandonment may occur in serious epidemic (Alegbejo, 2015).

2.3.2 *Tomato yellow leaf curl virus* (TYLCV)

TYLCV is the name given to a complex of virus species (based on the criteria of ICTV) causing tomato yellow leaf curl disease (TYLCD), is a member of genus *Begomovirus* of family *Geminiviridae* (Moriones and Navas-Castillo, 2000). It is one of the most devastating viruses cause diseases worldwide resulting in enormous economic losses to the growers. The disease is more commonly prevalent in tropical, sub-tropical and little warm temperate regions of the world, and is spreading to new areas. Severe outbreak reduce yield to zero leading to catastrophic losses in production (Noris *et al*., 1994, Pico *et al*., 1996; Polston and Anderson, 1997; Moriones, 2000). Currently the virus has also become the major threat to greenhouse production system worldwide.

TYLCV virions consist of a capsid which is not enveloped and is elongated and exhibits icosahedralsymmetry. It is geminate and has a diameter of 20 nm and appears hexagonal in outline. Virions consist of a capsid. (ICTVdB Management, 2006a).

TYLCV is transmitted from plant-to-plant by insect vector whitefly (*Bemisia tabaci* species complex) in a persistent circulative non propagative manner (Cohen and Nitzany, 1966; Morin *et al*., 1999). Usually, the young and adult whiteflies acquire the virus in 15-30 minutes during a feeding period (acquisition access) on an infected plant. These viruliferous (infective) whiteflies can then transmit/introduce the virus

into any number of healthy plants after about 24 hours of incubation (incubation period) within the insect during a feeding period of at least 15 minutes (inoculation access). The rate of transmission increases with longer acquisition and inoculation access periods. The virus retained in the whitefly for up to 20 days (throughout life) but it did not replicate in the insect vector and no transovarial transmission occur (Rubinstein and Czosnek, 1997). However, recently Ghanim *et al*. (2007) reported that TYLCV could be transmitted in a gender dependent manner during biotypes mating.In mechanical transmission, the virus could be successfully transmitted (100%) by grafting (Delatte *et al*. 2003). The whitefly vector has a very large number of hosts upon which it can feed and reproduce. Reservoirs of the vector may also vary among production regions (Jane *et al.,* 2007).The virus had been reported in Cyprus, India, Iraq, Israel, Jordan, Lebanon, Nigeria, Senegal, Sudan, Thailand, Tunisia, and Turkey (Dafalla, 2004; Lana and Wilson, 1976). It caused a wide range of symptoms including marginal leaf yellowing of leaf margin of the newest leaves, interveinal chlorosis, upward curling, and reduction in leaf size with puckering, shortening of internodes resulting in dwarf bushy appearance, excessive branching and stunting of the plants (Cohen and Antignus,1994).

2.3.3 *Pepper veinal mottle virus* (PVMV)

PVMV was first recognized as a distinct member of a group of viruses which was originally designated the *Potato virus Y* group but was later renamed the Potyvirus group (Harrison *et al.,* 1971). Virions consist of a capsid which is not enveloped but elongated with helical symmetry. It is filamentous, flexuous with a clear modal length with a length of 770 nm and a width of 12 nm. Axial canal is indistinct. There is one sedimenting component found in purified preparations. The sedimentation coefficient

is 155 S_{20w}. The thermal inactivation point (TIP) is at 55-60 °C. The longevity *in vitro* (LIV) is 7-8 days. Although the titer is dependent on the host, the decimal exponent (DEX) of the dilution end point is usually around 10^{-3} to 10^{-4}. The infectivity is not changed by treatment with ether (ICTVdB, 2006c).

PVMV occurs mainly in Africa. Although it affects *Capsicum annuum* L. crops in Afghanistan (Lal and Singh, 1988) and India (Nagaraju and Reddy, 1980). PVMV also infect other*Capsicum* spp. in Sierra Leone and Zaire, (Huguenot *et al*., 1997). PVMV has been reported in several West African countries, and in some parts of Nigeria (Alegbejo and Uvah, 1987; Fajinmi, 2006). There was a report that a strain of PVMV occurs naturally in *Telfairia occidentalis* (Cucurbitaceae) and *Solanum lycopersicum* (Solanaceae) in south western states and probably other pepper-producing states of Nigeria (Atiri, 1986; Alegbejo, 2015). Strains of the virus are also experimentally transmissible to at least 35 species of the Solanaceae and to nine species of five other families (Aizoaceae, Amaranthaceae, Apocynaceae, Chenopodiaceae and Rutaceae) (Brunt *et al*., 1978; Prasada *et al.,* 1979). Symptoms expressed by the leaves of PVMV infected plants include veinal chlorosis, followed by systemic interveinal chlorosis, mottle, and small distortion of leaves and at times leaf abscission and fruit distortion occur (Brunt *et al*., 1978).

PVMV, a potyvirus, is a major constrain to the cultivation of pepper in some parts of Nigeria (Alegbejo and Uvah, 1987; Fajinmi, 2006). It has been observed that in aphid-borne viruses, about 5 % of the infections occur during the primary spread by viruliferous aphids where the virus is introduced to the plant by aphids that pick up the virus from an external source such as a reservoir host. The other 95 % of the infections

are believed to occur during the secondary cycle where the virus is spread by aphids that acquired the virus within planting (Horvath and Nienhaus, 1982; Fajinmi, 2006).

2.3.4 *Cucumber mosaic virus* (CMV)

Cucumber mosaic virus is distributed worldwide. In Nigeria, it is found in southwestern and probably other states of the country. The virus is economically important but causes a minor disease of tomato in Nigeria (Alegbejo, 2015).CMV is an isometric single-stranded positive-sense tripartite RNA virus belonging to the genus *Cucumovirus*, family *Bromoviridae*. Morphologically CMV has rather characteristic 30 nm polyhedral particles with hollow centre (Palukaitis *et al*., 1992). Thermal inactivation point is 55-70 ^{0}C, longevity *in vitro* of1-10 days and dilution endpoint is 10^{-3} to 10^{-6} (Alegbejo, 2015). Genome consists of three plus sense single-stranded RNAs, packaged in separate particles. CMV particles contain about 18 % RNA. It consists of 4 RNAs. Only the largest RNA 3 is required for infectivity (Roossinck *et al*., 1999). The virions are not stable to freezing. Long-term storage of CMV is most reliable in the form of viral RNA, which is highly infectious, and very stable at −20 ºC (Roossinck and White, 1998). Although several strains of CMV have been identified based on host range and pathogenicity, two main subgroups, subgroup I and subgroup II, have emerged on the basis of serological relationships, peptide mapping of the coat protein, nucleic acid hybridization and nucleotide sequence identity (Palukaitis *et al*., 1992). Subgroup I was further divided into subgroup IA and subgroup IB on the basis of phylogeny estimations with full CP open reading frame (ORF), as well as rearrangements in the 5' non- translated region of RNA 3 (Roossinck *et al*., 1999).

CMV is efficiently transmitted in stylet-borne manner by over 80 species of aphid including: *Acrythosiphon* sp., *Aphis craccivora* Koch and *Myzus persicae* Sulzer

(Alegbejo, 2015). It is also mechanically transmissible to a wide range of test plant species of which cucumber (*Cucumis sativus* L.), *Nicotiana glutinosa* L., *N. benthamiana* L. and *Chenopodium quinoa* Wild are diagnostically most useful. Although, semi-persistent transmission has also been reported in Japan for some CMV strains and host species combinations (Kameya-Iwaki *et al.*, 2000) it was shown that *Myzus persicae* and *Aphis gossypii w*ere among the more efficient vectors of the virus (Palukaitis and Garcia-Arenal, 2003).

2.3.5 *Tobacco mosaic virus* (TMV)

Named after *Tobacco mosaic virus*, the genus *Tobamovirus* contains more than a dozen rod-shaped viruses measuring 18 by 300 nanometers (nm). Their genome consists of one positive single-stranded RNA (+ssRNA) of approximately 6,400 nucleotides (6.4 kb). Their protein coat consists of a single species of protein subunit arranged in a helix (Agrios, 2005). TMV/ToMV is a closely related virus that belongs to the family *Virgaviridae* and is the type member of the plant virus genus *Tobamovirus*. Substantial losses to greenhouse and field produced tomato can be caused by TMV (ICTV, 2012). TMV is a stable, persistent virus most commonly introduced into plants through small wounds caused by physical contact (mechanical transmission) (Pfleger and Zeyen, 2008). The symptoms induced in tomato by TMV vary greatly depending upon the variety, virus strain, and time of infection, light intensity and temperature. Symptoms appear as light and dark green mottled areas. Leaves of infected plants are often small, curled and puckered (Zitter, 1984; Sikora, 1998; Averre and Gooding, 2000). Plants infected early in their development are stunted. The disease can reduce size and number of fruits produced; the fruit do not show malformations. However, occasionally mottling, bronzing and internal browning

occurs (Zitter, 1984; Sikora, 1998; Averre and Gooding, 2000). The most important sources of inoculums for TMV are contaminated leaf, root debris and seed (Sikora, 1998).

The virus is transmitted by mechanical inoculation, grafting, contact and through seed. Geographical distribution includes all tobacco-growing areas of Nigeria (Kaduna, Kogi, Kwara, and Oyo states etc.). The virus reduces the quantity and quality of leaf produced resulting in considerable loss in revenue (Alegbejo, 2015).

2.3.6 *Potato virus Y* (PVY)

Potato virus Y (PVY) is the type species of the genus *Potyvirus* of the family *Potyviridae*. This virus causes serious losses in many important crops worldwide, especially in solanaceous plants such as potato (*Solanum tuberosum* L.), pepper (*Capsicum annuum* L.), and tobacco (*Nicotianatabacum* L.). Virions have a buoyant density in CsCl of 1.323 g cm $^{-3}$ (strain Y ^{O}), or 1.326 g cm^{-3} (strain Y ^{N}). There are 1 sedimenting component(s) found in purified preparations. The sedimentation coefficient is 145 S 20w. A 260/A 280 ratio is 2.3 or 2.9. The thermal inactivation point (TIP) is at 50-62°C and the longevity in vitro (LIV) is 7-50 days. Although the titer is dependent on the host, the decimal exponent (DEX) of the dilution end point is usually around 2-6 (ICTVdB Management, 2006d).

Three PVY strains are recognized by their distinct host responses: the common strain (PVY^{O}), which causes mosaic and mottling symptoms in *N. tabacum* plants; the tobacco veinal necrosis strain (PVY^{Y}), causing necrotic symptoms in *N. tabacum*; and the stipple streak strain (PVY^{C}), characterized by the hypersensitive reaction in many

potato cultivars (De Bokx and Huttinga, 1981). *Potato virus Y* (that infects tomato), has long flexuous rod-shaped particles (730 x 11 nm) containing single-stranded RNA. *Potato virus Y* occurs in several pathotypes (Jones *etal.,* 1991), which are transmitted by aphids in a non-persistent manner. Typical symptoms of PVY in tomato include mosaic, vein chlorosis, mild mottling and dark brown necrosis on leaflets, severe necrosis, leaf crinkling, and drooping (Jones *et al*., 1991).

2.3.7 *Tomato mosaic virus* (ToMV)

Among the prevalent tobamoviruses, ToMV is the most important and commonly associated with tomato crop and is distributed throughout Pakistan (Khan, 1997). The virus is a stable and wide-spread RNA virus that infects plant species (Hollings and Huttinga 1976). It generally causes mosaic and leaf curling on leaves, uneven ripening and internal browning or brown wall on fruits of certain varieties.Consequently, it is not easy to correctly identify ToMV based on symptoms because it causes a variety of them. However, known common ToMV symptoms include mosaic, systemic chlorosis, local necrotic lesions, leaf abscission, as well as systemic leaf and stem necrosis, which ultimately cause death (Brunt *et al.,* 1990; Jones *et al.,* 1991). *Tomato mosaic virus* (ToMV) distinguished from TMV by its ability to produce local necrotic lesions in *Nicotiana tabacum* var. White Burley and N. sylvestris (Green and Kim, 1991). ToMV strains include those, which cause corky ring, crusty fruit, yellow streak and aucuba symptoms (Kang *et al*., 1981; Jones *et al*., 1991). The virus was tentatively identified on the basis of symptoms developed in the infected plants. An average incidence of 29.79 and 25.49 % of ToMV was recorded in tomato leaves and seeds, respectively (Khan, 1997). ToMV virions consist of a capsid not enveloped. The nucleocapsid is elongated with helical symmetry that is rod-shaped, straight with a

clear modal length with a length of 300 nm and a width of 18 nm. Virus is not transmitted by a known vector but transmitted by mechanical inoculation, grafting, contact between hosts and seeds (Buchen-Osmond, 2003). *Tomato mosaic virus* provokes a serious disease in tomato plants of infected susceptible cultivars can be reduced by up to 25 %. In spite of existing resistant varieties, susceptible cultivars are commonly cultivated. Apart from resistant varieties, an alternative means of protection should be sought to resolve the ToMV problem faced by tomato growers (Eraslan *et al*., 2007).

2.3.8 *Tomato aspermy virus* (TAV)

TAV belongs to the genus Cucumovirus that also includes *Cucumber mosaic virus* (CMV) and *Peanut stunt virus* (PSV) in family *Bromoviridae*. The virus was originally described by Blencowe and Caldwell (Blencowe and Caldwell, 1994). Although the virus was isolated from tomato (*S.lycopersicum*), the authors stated that the virus may have been transmitted to tomato from chrysanthemum stock (*Chrysanthemum morifolium* Ramat, Hemsl.) in which it causes a severe flower break or distortion. It reportedly causes severe systemic leaf mottling, enation, dwarfing and seedlessness or aspermy in infected tomato (Blencowe and Caldwell, 1994). Aspermy viruses have continued to be called TAV despite the fact that most isolates are recovered from chrysanthemum, in which they cause severe flower break or distortion (Hollings and Stone, 1971). A less extensively studied cucumovirus is tomato aspermy virus (TAV), which can be differentiated from CMV (Habili and Francki, 1974) although both viruses are closely related in several properties (Habili & Francki, 1974; Jaegle *et al.*, 1990)

Tomato aspermy virus (TAV) is an important agent of chrysanthemum disease throughout the world (Kaper and Waterworth, 1981; Shi *et al*., 1993). TAV contains a single stranded RNA genome of messenger-sense divided into three species, RNAs 1, 2 and 3 (Murphy *et al*., 1995). Virions of the virus contain 21.2 % nucleic acid 78.8 % protein; 0 %lipid.Genome consists of RNA single-stranded and has thermal inactivation point (TIP) of 50-60 °C, longevity *in vitro* (LIV) of 2-6 days and dilution end point (DEP) of $\log_{10}$ minus 4-6.The virus is transmitted by a vector called *Myzus persicae* andmany other species of family Aphididae (Kennedy *et al*., 1962). It is also transmitted in a non-persistent manner, mechanical inoculation, bygrafting but not transmitted by contact between plants;transmitted by seed (Brunt *et al.*, 1996).

2.4 Management of Tomato Viruses

Important management strategies include keeping the field free of weeds, the use of cross protection, spraying the field with mineral oil, transplanting only healthy seedlings, removal and destroying early infected plants, planting early to avoid heavy aphid infestation later in the season, planting resistant varieties, removal and destruction of weed hosts of the virus within and around the field (Alegbejo, 2015). According to Palumbo *et al*. (2001), cultural and biological pest management strategies provide the best options for controlling the vectors and overcoming the problem of insecticide resistance. As such, various cost effective measures have been reported for controlling tomato virus diseases. They include cultural practices, vector manipulation, inoculum source elimination or phytosanitation, cross-protection, use of resistant varieties or even transgenic plants, and virus or vector exclusion (Mason *et al*., 2000; Hilje *et al*., 2001; Lapidot and Friedmann, 2002; Greer and Dole, 2003; Yang *et al*., 2004; Mutwiwa *et al*., 2005).

2.5 Alternative hosts of viruses of tomato

Tomato yellow leaf curl virus (TYLCV) has a very wide host range. Nono- Womdim *et al.* (1996) detected it in a number of weed species in Tanzania, which are alternative TYLCV hosts.In addition to tomato, the following plants have been reported as hosts of TYLCV. Family Solanaceae*: Capsicum annuum* L., *C. frutescens* L., *Datura stramonium* L., *D.bernhardii* Lundstr., *Lycopersicon peruvianum* L., *L. hirsutum* Dunal, *L. pimpinellifolium* L., *Nicotianasylvestris* Speg and Comes, *N. benthamiana* Domin, *N. glutinosa* L., and *N. tabacum* L, and *Solanum nigrum* L. Family Malvaceae*: Malva arvensis* L., *M. nicaensis* L., *M. parviflora* L., *Corchorustinctorius* L., *Hibiscus syriacus* L., and *Gossypium hirsutum* L. Family Fabaceae*: Arachis hypogaea* L., *Lens esculenta* Moench, *and Phaseolus vulgaris* L. Family Pedaliaceae: *Sesamum indicum* L.. Family Asteraceae*: Sonchus oleraceus* L. Family Euphorbiaceae*: Euphorbia heterophylla* L. Family Acanthaceae*: Achyranthes aspera* L. *Others: Chaerogphyllum spp., Cynanchum acutum* L., *Hyoscyamus desertorum* L., *Nicandra physaloides* (L.) Gaert, *and Vitis vinifera* L. (Cohen and Nitzany, 1966;Nitzany, 1975; Nakhla *et al*., 1978; Cohen and Antignus, 1994; Nakhla *et al*., 1994; Nono- Womdim *et al*., 1996).

The following plants have been reported as hosts of *Tomato leaf curl viruses*: Family Solanaceae*: Capsicum annuum* L., *C. frutescens* L., *Datura stramonium* L., *D.bernhardii* Lundstr., *Lycopersicon peruvianum* L., *L. hirsutum* Dunal, *L. pimpinellifolium* L., *Nicotianasylvestris* Speg and Comes, *N. benthamiana* Domin, *N. glutinosa* L., and *Nicotiana tabacum* L. *vars Samsun* and *Havana,* and *Solanum nigrum* L. Family Malvaceae*: Malva arvensis* L., *Malva nicaensis* L., *M. parviflora* L., *Corchorustinctorius* L., *Hibiscus syriacus* L., and *Gossypium hirsutum* L. Family

Fabaceae*: Arachis hypogaea* L., *Lens esculenta* Moench, *and Phaseolus vulgaris* L. Family Pedaliaceae: *Sesamum indicum* L.. Family Asteraceae*: Sonchus oleraceus* L. Family Euphorbiaceae*: Euphorbia heterophylla* L. Family Acanthaceae*: Achyranthes aspera* L. *Others: Chaerogphyllum spp., Cynanchum acutum* L., *Hyoscyamus desertorum* L., *Nicandra physaloides* (L.) Gaert, *and Vitis vinifera* L. (Cohen and Nitzany, 1966;Nitzany, 1975; Nakhla *et al*., 1978; Cohen and Antignus, 1994; Nakhla *et al*., 1994; Nono- Womdim *et al*., 1996).

Tomato aspermy virus has wide host range which includes *Chenopodium amaranticolor* Coste and Reyn,*C. quinoa* Willd, *Chrysanthemum morifolium* Ramat,*Cucumis sativus* L., *Lycopersicon esculentum* Mill, *Nicotiana clevelandii* L., *N. glutinosa* L., *N.* L., *Phaseolus vulgaris* L., *Stellaria media* L. and *Vigna unguiculata* L. (Brunt *et al.,* 1996).

Cucumber mosaic virus (CMV) has one of the broadest host ranges. CMV (as a type species of the genus *Cucumovirus* in the family *Bromoviridae*)is reported to infect over 1000 plant species worldwide causing viral epidemics in several economically important crops (Palukaitis and Garcia-Arenal, 2003). Some of the families and species are: Amaranthaceae, Chenopodiaceae, Asteraceae, Cucurbitacceae, Fabaceae, Solanaceae and *Gomphrena globosa* L., *C. amaranticolor*, *Tagetes erecta* L., *Cosmos sulphureus* Cav., *Cosmos bipinnatus* Cav., *Zinnia elegans* Jacq., *Cucumis sativus* L., *Citrullus lanatus* (Thunb), Matsum and Nakai, *Lagenaria siceraria* Molina, *Trichosanthes anguina* L., *Cucurbita moschata* Duchesne ex Poir, *Luffa acutangula* (L.) Rosxb., *L. cylindrical* M. Roem, *Benincasa hispida* (Thunb) Cogn, *Phaseolus vulgaris* L., *Pisum sativum* L., *Vigna unguiculata* L., *Nicotiana glutinosa* L.,

Nicotiana tabacum L., *Nicotiana rustica* N., *Lycopersicon esculentum* Mill, *Physalis floridana* Rydb., *Petunia hybrid* Hort., *Datura metel* DC.and*Datura stramonium* L.(Parvin *et al*., 2007).

Under experimental conditions susceptibility to infection by PVMV was found in several families: Alliaceae, Amaranthaceae, Apocynaceae, Chenopodiaceae, Asteraceae, Brassicaceae, Cucurbitaceae, Poaceae, Lamiaceae, Fabaceae, Phytolaccaceae, Rutaceae, Solanaceae. The following species were susceptible: *Ageratum conyzoides* L., *Allium cepa* L., *Brassica campestris* ssp. *pekinensis*, *Brassica juncea* L., *Brassica oleracea* var. *capitata*, *Calendula officinalis* L., *Capsicum annuum* L., *Capsicum frutescens* L., *Catharanthus roseus* (L,) G. Don, *Celosia argentea* L., *Chenopodium amaranticolor* Coste and Reyn, *C. foetidum* Schrad, *C. quinoa* Willd, *Citrus paradise* Macfad, *Crotalaria spectabilis* L., *Cucumis melo* L., *Cucumis sativus* L., *Datura metel* DC., *Datura stramonium* L., *Emilia sagittata* DC., *Glycine max* L., *Gomphrena globosa* L., *Helianthus annuus* L., *Lactuca sativa* L., *Lycopersicon esculentum* Mill., *Nicotiana benthamiana* L., *N. clevelandii* L., *N. megalosiphon* Van Heuch and Muell, *N. occidentalis* Wheeler, *N. sylvestris* Spegazz, *N. tabacum* L., *Ocimum basilicum* L., *Petunia x hybrid* Wave, *Phaseolus vulgaris* L., *Physalis angulata* L., *Physalis floridana* L., *Phytolacca Americana* L., *Solanum integrifolium* L., *Solanum melongena* L., *Solanum nigrum* L., *Solanum tuberosum* L., *Trifolium incarnatum* L., *Verbesina encelioides* Cav., *Vicia faba* L., *Zea mays* L.and *Zinnia elegans* L. (ICTVdBManagemen, 2006c).

In the Family Chenopodiaceae, Solanaceae: Cucurbitaceae, Fabaceae. The following species were susceptible to ToMV*: Capsicum annuum* L., *C. frutescens* L., *C.*

amaranticolor, *C. murale* L., *C. quinoa* Schrad, *Datura metel* DC., *Lycopersicon esculentum* Mill, *L. pimpinellifolium* L., *N. benthamiana* Domin, *N. clevelandii* A. Gray, *N. glutinosa* L., *N. megalosiphon* Van Heuch and Muell, *N. rustica* N., *N. tabacum* L., *Petunia x hybrida* Wave, *Physalis floridana* Rydb., *P. peruviana* , *Solanum giganteum* L., *S. melongena* L., *S. nigrum* L.It is distributed worldwide, whenever tomato is grown (ICTV Management, 2006b).

Tobacco mosaic virus (TMV) has a moderate host range including many solanaceous species. Under experimental conditions susceptibility to infection by TMV is found in many families. Susceptible host speciesare has been reported in the Family *Chenopodiaceae*, *Asteraceae*,*Cucurbitaceae*, Fabaceae, *Papaveraceae*and *Solanaceae*. The following species were susceptible to virus infection: *Beta vulgaris* L., *Capsicumfrutescens* L.,*Chenopodium hybridum* L.,*C. quinoa* Willd, *Cucumis melo* L., *C. sativus* L., *Cucurbita pepo* L., *Datura stramonium* L., *Lactuca sativa* L., *Lycopersicon esculentum* Mill, *Lycopersicon pimpinellifolium* L., *Nicotiana benthamiana* Domin, *N. clevelandii* A. Gray, *N. glutinosa* L., *N. megalosiphon* Van Heuch and Muell, *N. rustica* N., *N. tabacum* L., *Petunia x hybrida* Wave, *Physalis floridana* Rydb., *P. peruviana* , *Solanum giganteum* L., *S. melongena* L., *S. nigrum* L.

Pepper veinal mottle virus (PVY) has a wide host range. It infects 405 species in 72 genera of 31 including 287 species in 14 genera of the Solanaceae, such as pepper, tomato, eggplant, and tobacco. *Capsicum annuum* L., *Capsicum frutescens* L., *Chenopodium amaranticolor*Coste and Reyn,, *C. quinoa* Willd, *Dahlia* spp., *Datura metel* DC., *D. stramonium* L., *Lycopersicon esculentum* Mill., *Nicotiana glutinosa* L., *N. tabacum* L., *Physalis floridana* Rydb., *Solanum chacoense* L., *S. demissum* L., *S.*

demissum × *S. tuberosum* L., *Tinantia erecta*, *Lycium* sp., *Hyocyamus niger* L.,*Nicandra* sp. and *Petunia* sp. (ICTVdB, 1995-1999d;Alegbejo, 2015).

2.6 Diagnosis of Tomato Viruses

Under field situations, the most obvious viral symptoms are mosaic, mottling, necrosis and leaf distortions, but for identification of symptom causing viruses, these features are not very reliable on their own because they are influenced by a number of other factors such as sucking insect pest infestation, and plant-water relations (Green, 1991). Consequently, several laboratory methods have been developed to identify viruses (Matthews, 1991). These include the use of test plants, serology, and various molecular tests.

2.6.1 Bioassay of tomato viruses

Test plants are diagnostic tools mostly used to detect sap-transmitted viruses. For example, the World Vegetable Center (AVRDC) in Taiwan uses this kind of technique (Green, 1991). Some examples of test plants include *Capsicum annuum, C. frutescens,Chenopodium quinoa, C. amaranticolor, Cucumis sativus, Gomphrena globosa,Lycopersicon esculentum, Nicotiana tabacum, N. rustica, Petunia hybrida, Phaseolusvulgaris,* and *Pisum sativum* (Brunt *et al.*, 1990). These test plants are used especially to confirm virus infection, but may not tell the actual virus causing the problem. Therefore, the technique is not very efficient for taxonomy. Moreover, it is time consuming. As such, serological tests are preferred (Bock 1982).

2.6.2 Serological tests of tomato viruses

The micro-precipitin serological test was one of the first serological methods used for laboratory identification of viruses (Duncan and Torrance, 1992). It is an expensive test in terms of the need for large quantities of antisera. It is less sensitive than enzyme-linked immunosorbent assay (ELISA), though easier to use. ELISA is a serological test that uses antiserum prepared against a particular virus. The antiserum contains antibodies generated in blood serum of rabbits inoculated with that particular virus' antigen, and can be made in a local and simple laboratory. This antiserum and alkaline buffers are used on microtiter plastic plates to test plant sap for that specific virus (Clark and Adams, 1977). Another serological test is the Ouchterlony Agar Gel Double Diffusion test (Matthews, 1991). It is a simple test, useful for identifying viruses. It uses crude antisera, which contain immunoglobulin M (IgM) and immunoglobulin G (IgG). In addition to the above techniques, immunoelectron microscopy can be used to identify individual viruses occurring in a single plant sap extract at the same time, and also to study virus particle size and shape (Duncan and Torrance, 1992). Furthermore, there is the Double-antibody-sandwich Enzyme-linked immunosorbent assay (DAS-ELISA) used for immediate serological identification of viruses in a sample, based on viral protein differences (Clark and Adams, 1977). DAS-ELISA is widely used. The reagents and chemicals required are readily available, and it gives adequate identification of viruses. Like all other ELISAs, it is fairly cheap, especially if antisera can be produced locally and do not have to be bought from commercial companies. Triple-Antibody-Sandwich (TAS-ELISA) is another form of ELISA. It uses monoclonal antibodies to detect viruses such as tomato geminiviruses (Credi *et al.*, 1989; Roberts *etal.*, 1984; Thomas *et al.*, 1986). TAS is efficient and easy to conduct in conditions of limited time and space. Macintosh *et al.* (1992) used

TAS to study tomato geminiviruses in Europe. It is more specific and more sensitive than DAS, because of the monoclonal antibodies used. Like DAS, it is fairly cheap (Matthews, 1991), though not as molecular techniques.

2.6.3 Molecular tests of tomato viruses

Recently, molecular techniques have been developed to identify viruses. Polymerase Chain Reaction (PCR) is one of these techniques (Duncan and Torrance, 1992). It is based on differences between viral nucleic acid, very efficient and accurate depending on the type of primers used (specific or general) (Lewin, 1997). However, it is an expensive technique because of the high cost equipment and reagents (Maniatis *et al.*, 1982). The nucleic acid hybridisation test is another molecular technique for identifying viruses that cannot be differentiated by using serology (Czosnek *et al.*, 1988). It is efficient, but uses expensive reagents and chemicals. It requires special expensive laboratory facilities, especially if it uses radioactive probes (P^{32}) and not non-radioactive (biotin) ones. Furthermore, DNA hybridisation is very useful in that it can be used to test samples sent from normally poorly equipped laboratories in developing countries to advanced laboratories. One way of quickly differentiating geminiviruses is by sequence pairwise comparison and phylogenies (Padidam *et al.*, 1995; Brown, 1997; Fauquet *et al.*, 2003). However, there are different opinions. Brown(1997) reported that sequence comparisons could be based on the intergenic region and coat protein gene in the absence of a complete DNA sequence, while others feel that full sequence comparisons (Fauquet *etal.*, 2003) are necessary. In the absence of adequate resources, the former approach to geminivirus identification would be most appropriate for developing countries, whereas complete sequence comparisons would be encouraged, where possible. Based on results obtained by using the above

techniques, and under the coordination of the International Committee for the Taxonomy of Viruses (ICTV), tomato viruses have been characterized and grouped in orders, families, genera and species (Padidam *et al.*, 1997; Fauquet and Mayo, 1999; Pringle, 1999; Mayo and Brunt, 2005).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Survey and sampling of tomato fields

Surveys were conducted in the month of February, 2016 dry season to document the occurrence, distribution and alternative hosts of viruses on plants in Sokoto and Zamfara States. Three Local Government Areas (LGAs) were surveyed per state for disease incidence and three farms were visited per LGA. The LGAs were selected on the basis of high production figuresand with advice of Extension Agents. For Sokoto State, the LGAs were Raba, Kware and Tureta while Tsafe, Talata Mafara and Bakura LGAs were surveyed in Zamfara State. The maps of Local Government Areas in Sokoto and Zamfara States surveyed are shown in Figures 1 and 2 respectively. In each farm, five quadrants 4 m x 4 m were demarcated at four ends of the field and one at the centre. Total number of plants was recorded using the method of Kashina *et al*. (2002a) and field disease incidence was calculated.

Virus incidence (VI) in laboratory was recorded as the number of positive samples in the total number of samples in the study plot. The percentage incidence was calculated using the formula below (Chaube and Pundhir, 2005);

$$\text{Virus incidence } (\%) = \frac{\text{Number of positive samples}}{\text{Total number of samples examined}} \times 100$$

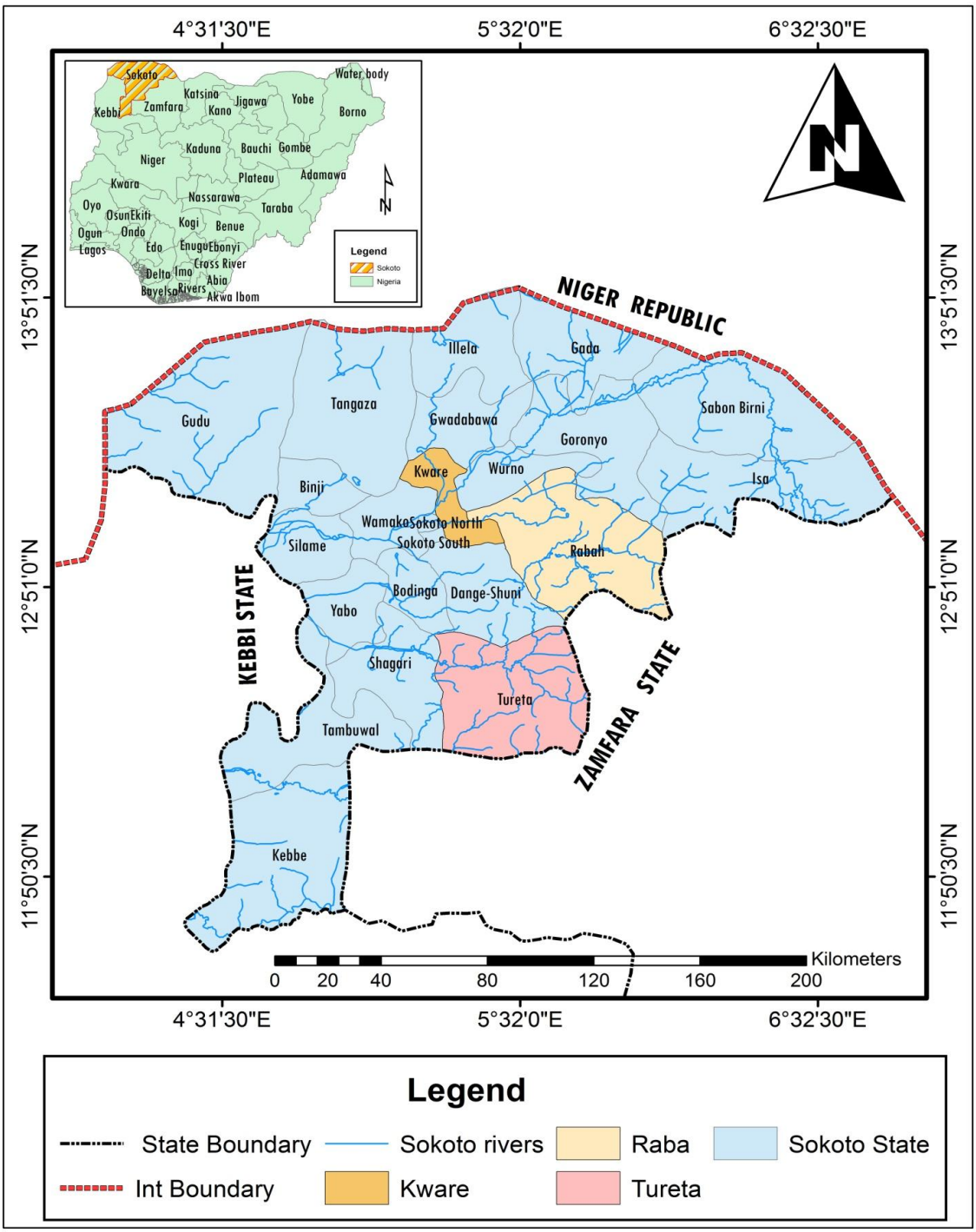


Figure 1: Local Government Areas in Sokoto State surveyed for viruses of tomato, 2016 dry season (Source: G I S Geography Laboratory, ABU).

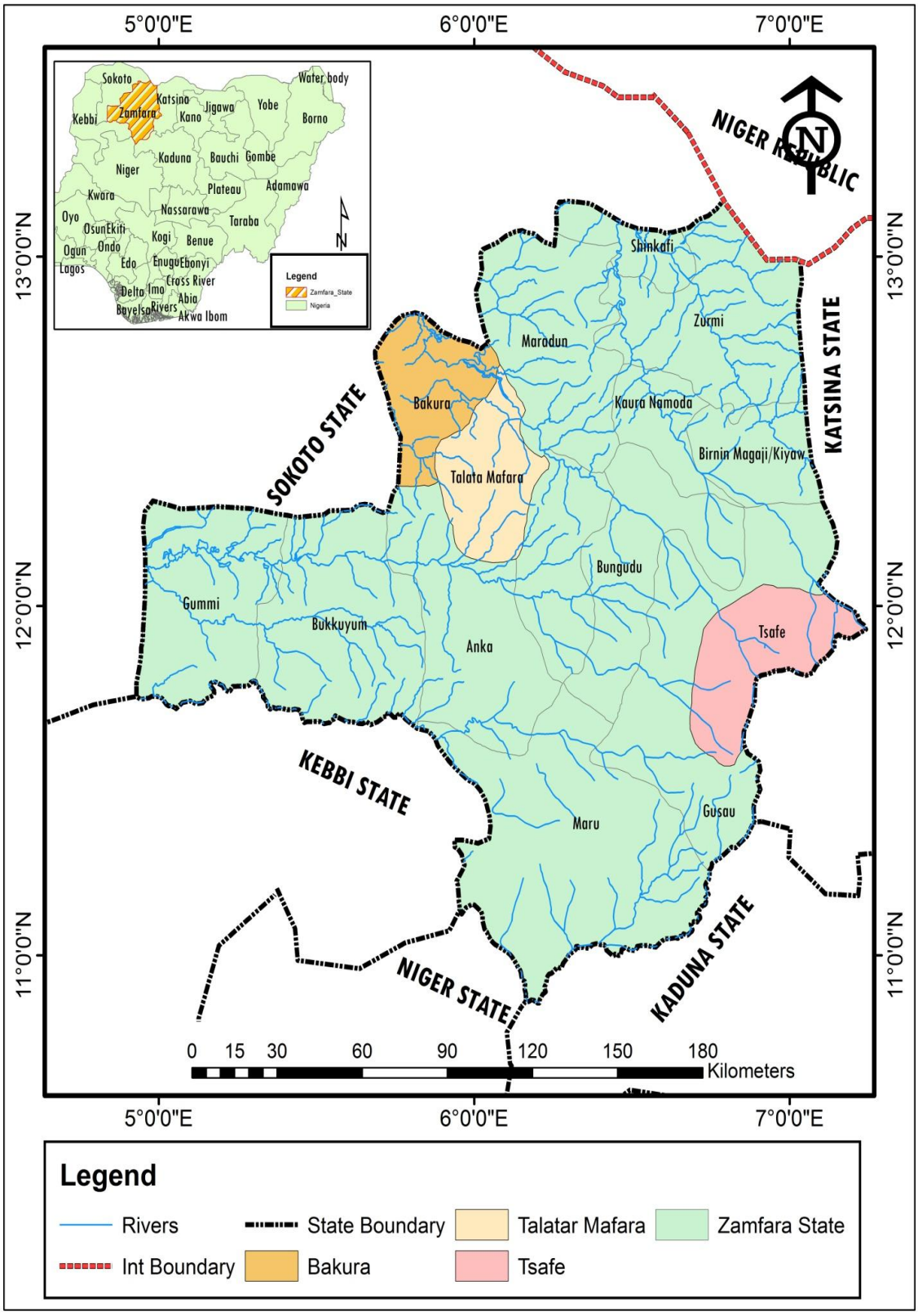


Figure 2: Local Government Areas in Zamfara State surveyed for viruses of tomato, 2016 dry season(Source: G I S Geography Laboratory, ABU).

Fifteen leaf samples of both symptomatic and asymptomatic plants were collected from each field, labelled and put in polyethylene bags. Leaf samples collected were placed in an ice chest. During the survey, weeds and other crop plants within and around (five metres)the farms were sampled and randomly collected, labelled, put in polyethylene bags, stored in an ice chest and transported to the Virology Laboratory,Department of Crop Protection, ABU, Zaria. Survey for weed hosts of viruses was repeated during wet season, July 2016. The weed plantswere identified to species level in the Herbarium (Plant Collection) Botany Unit, Faculty of Science, Usmanu Danfodiyo University Sokoto.

A structured questionnaire was administered to farmers visited and dataon the following data were collected: Name of LGA, farm location, co-ordinate, elevation, size and agronomic data such as cropping history, cropping pattern, crops surrounding the farm, crop protection practices employed, field hygiene, age of the crop, observed symptoms on both tomato and alternative hosts, source of seed, and the varieties of tomato crop grown (Appendix I).

3.2 Laboratory Detection of Viruses of Tomato

3.2.1 Procedure for double antibody sandwich (DAS) ELISA for detection of *Tomato aspermy virus* (TAV) and *Tomato mosaic virus* (ToMV).

ELISA plates were coated with two hundred microlitre of polyclonal antibody diluted at 1:1000 in carbonate buffer. The plates were covered and incubated at 37 ^{0}C for 2 hours and then washed three times with PBS-Tween 20 (PBS-T) by flooding three times, drained and tapped dry. Two hundred microlitre of 2 % skimmed milk in PBS-Tween was added into each well to block the uncoated sites. The plates were covered and incubated at 37 ^{0}C for 30 min. The blocking solution was then removed and tapped dry. Tomato leaf samples were extracted in extraction buffer by grinding samples in extraction buffer (1: 20 w/v). Two hundred microlitre aliquots of the test samples were added to duplicate wells. The plates were covered and incubated at 37 ^{0}C for 2 hours. Then, the plates were washed three times with PBS-T by flooding three times, drained and tapped dry. The same procedure was used for leaves of weed samples collected during dry and wet seasons.. Two hundred microlitre of the monoclonal antibody (MAb) diluted in conjugate buffer was then added to each test well. The plates were covered, incubated at 37 °C for 2 hours and washed as described earlier. Two hundred microlitre of p-nitrophenyl phosphate substrate was added per well and incubated at room temperature in the dark for 1 hour. The plates were read after 1 hour, using spectrophotometric measurement of absorbance at A_{405} nm (Clark and Adams, 1977).ELISAvalues at least twice that of the negative control (check) were rated positive according to Kumar (2009).

3.2.2 Triple antibody sandwich (TAS)-ELISA for detection of *Tomato yellow leaf curl virus* (TYLCV).

ELISA plates were coated with two hundred microlitres of polyclonal antibody diluted at 1:1000 in carbonate coating buffer. The plates were covered and incubated at 37 ^{0}C for 2 hours and then washed three times with PBS-T by flooding three times, drained and tapped dry. Two hundred microlitres of 2 % skimmed milk in PBS-Tween was added into each test well to block the uncoated sites. The plates were covered and incubated at 37 ^{0}C for 30 min. The blocking solution was then removed and tapped dry. The same procedure was used for leaves of weed samples collected during dry and wet seasons. Leaf samples were extracted (0.05 M Tris containing 0.06 M sodium sulfite, pH 8.5) by grinding samples in extraction buffer (1: 20 w/v) two hundred microlitres aliquots of the test samples were added to duplicate wells. The plates were covered and incubated at 37 ^{0}C for 2 hours. The plates were then washed three times with PBS-Tween by flooding three times, drained and tapped dry. Two hundred microlitres of the monoclonal antibody (MAb) was added in conjugate buffer to each well. The plates were covered and incubated at 37 °C for 2 hours. The plates were then washed 3 times with PBS-T by flooding 3 times, drained and tapped dry. Two hundred microlitres of rabbit anti-mouse alkaline phosphatase (RAM-AP) diluted at 1:1000 in conjugate buffer was added into the plates. The plates were covered and incubated at 37 ^{0}C for 2 hours, and washed times with PBS-Tween by flooding washed times, drained and tapped dry. Two hundred microlitres of p-nitrophenyl phosphate substrate was added per well and incubated at room temperature in the dark for 1 hour. The plates were read after 1 hour, using spectrophotometric measurement of absorbance at A_{405} nm (Clark and Adams, 1977).ELISAvalues at least twice that of the negative control (check) were rated positive according to Kumar (2009).

3.4 Data analysis

Data collected during the survey from the two States were subjected to descriptive statistics (bar and pie charts) using Microsoft Excel (2010 version).

CHAPTER FOUR

4.0 RESULTS

4.1 Incidence of TomatoViruses in Sokoto and Zamfara States.

Different symptoms observed on tomato plants duringsurvey were leaf curl, mosaic, mottling, distortion, stunting, chlorosis and necrosis. Other symptoms observed were mixture of the abovenecrotic symptoms on tomato plant infected by TAV, mosaic symptom on tomato induced by ToMV, leaf curl and distortion caused by TYLCV, mixed infection caused by TAV and TYLCV, mixed infection caused by TAV and ToMV, mixed infection caused by ToMV and TYLCV, mixed infection caused byTAV, ToMV and TYLCV. The symptoms caused by the TAV, ToMV and TYLCV are shown in Plate IA, IB and ICrespectively. In order to confirm the fact that symptoms observed on tomato were indeed due to viruses, serological tests were conducted. DAS and TAS – ELISA results indicated that samples that tested positive for TAV, ToMV and TYLCV either had curl, mosaic, mottling, distortion, stunting, chlorosis or necrosis. Viruses occurred singularly or in mixture of two or three viruses in one sample.Data collected during the survey are presented in appendices III and IV, V and VI respectively.







Plate I: A = **N**ecrotic symptomplant caused by TAV (arrow); B=yellowing symptom on tomato induced by ToMV (arrow); C = leaf curl caused by TYLCV (arrow)on tomato.

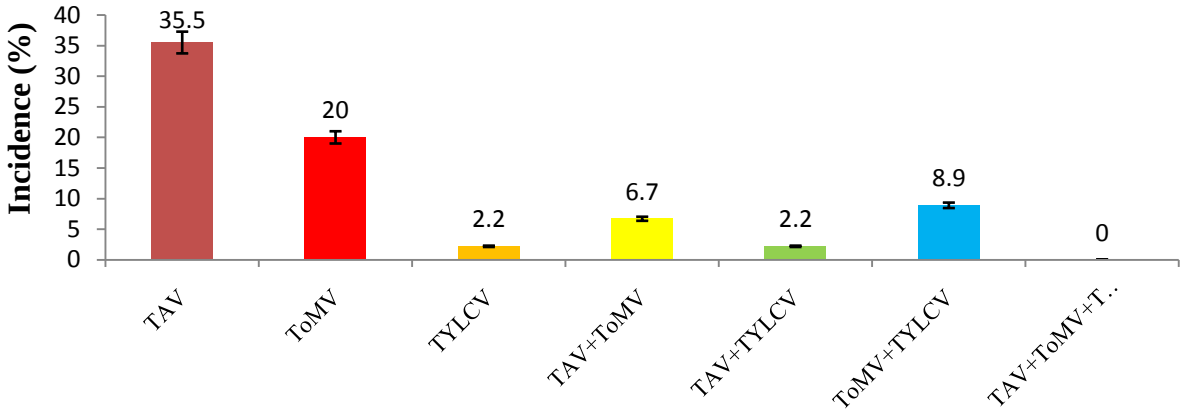
4.1.1 Incidence of tomato in virusesthree Local Governments of Sokoto State.

ELISA result showed that out of forty five samples tested from Raba LGA thirty four were positive.*Tomato aspermy virus* (TAV) had the highest incidence of the 35.5 % followed by *Tomato mosaic virus* (ToMV) with incidence of 20 % while 2.2 %incidence was recorded for *Tomato yellow leaf curl virus* (TYLCV).The TAV + ToMV had incidence of 6.7 %, TAV +TYLCV (2.2 %), ToMV + TYLCV (8.9 %) while no incidence was detected for TAV + ToMV + TYLCV as shown in Figure 3A.

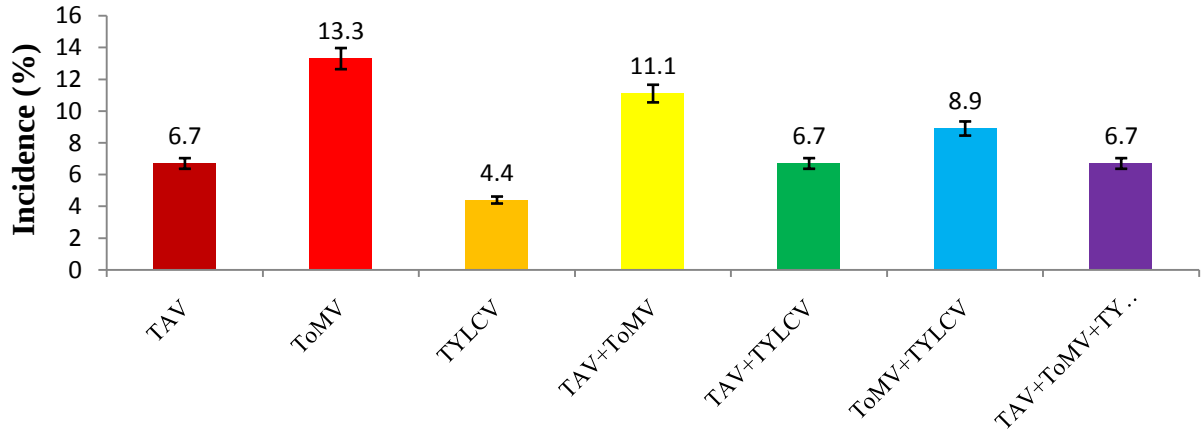
In KwareLocal Government Area, twenty six samples tested positive out of forty five. ToMVhad the highest incidence of the 35.5 % followed byTAV + ToMV (11.1 %)and least by TYLCV (4.4 %). TAV + ToMV had incidence of 11.1 %, TAV, ToMV + TYLCV (8.9 %). TAV + TYLCV, and TAV + ToMV + TYLCV had same incidence of 6.7 % (Figure 3B).

Twenty foursamples tested positive out of forty five in Tureta Local Government, ToMV was recorded to have the highest incidence of 24.4 % followed by TAV and ToMV + TYLCV with similar incidence of 8.9 % respectively. least incidence byTAV + TYLCV (2.2 %). 4.4 % was recorded TYLCV. TAV + ToMV hadincidence of 4.4 % while no incidence ofTAV + ToMV + TYLCV was detected in the samples(Figure 3C).

(A) Raba LGA



(B) Kware LGA



(B) Tureta LGA

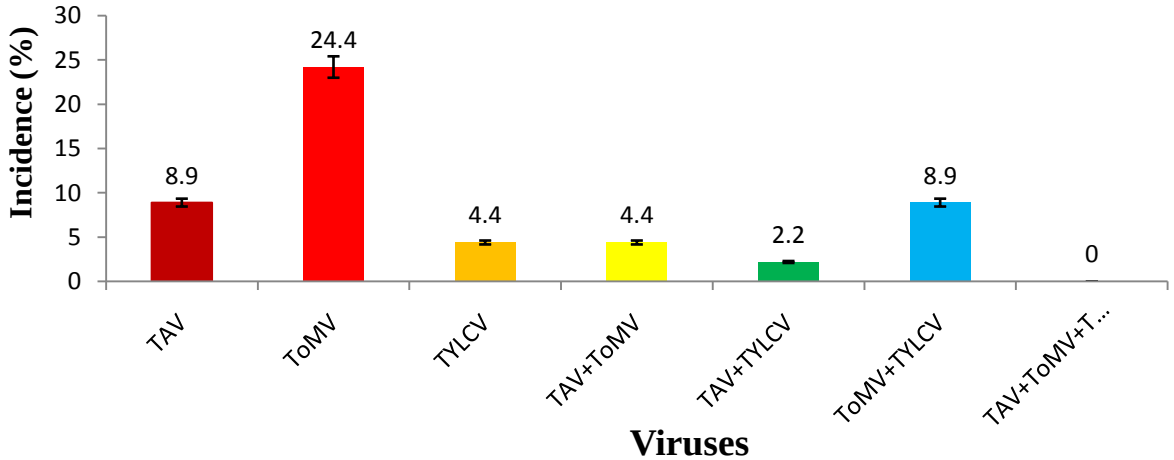


Figure 3: Incidence of tomato viruses in (A) Raba (B) Kware (C) Tureta Local Government Areas of Sokoto Stateduring the 2016 dry season.

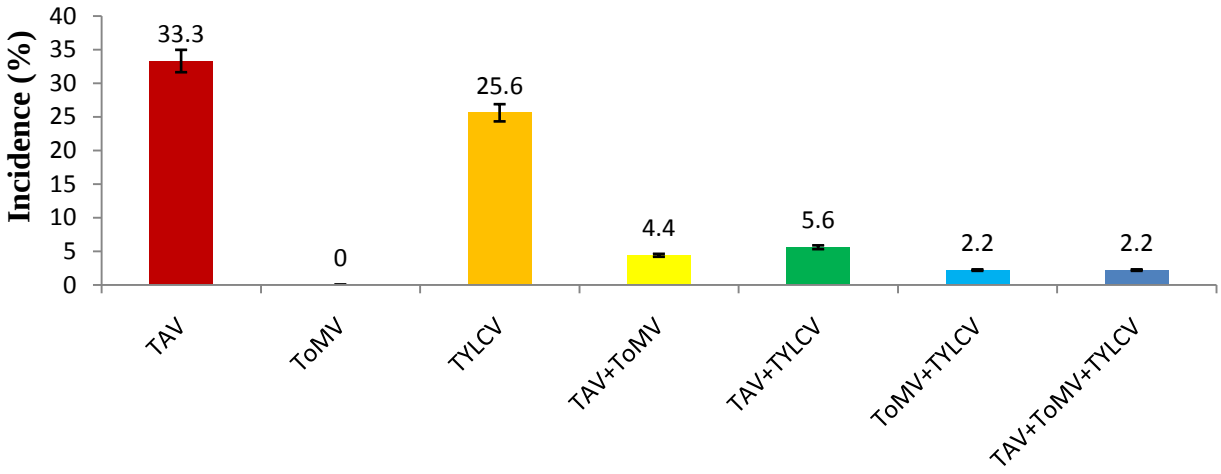
4.1.2 Incidence of tomatovirusesin three Local Government Areas of Zamfara State.

ELISA results for tomato leaf samples collected in Tsafe Local Government indicated that out of forty five samples tested, thirty three were virus infected. TAV had the highest incidence of 33.3 % followed by TYLCV with incidence of 25.6 %. TAV + TYLCV had incidence of 5.6 %, TAV + ToMV (4.4%) whileTAV + TYLCV andTAV + ToMV + TYLCV had similar incidence of 3.3 %. No single incidence ofToMV was detected in the Local Government Area (Figure 4A).

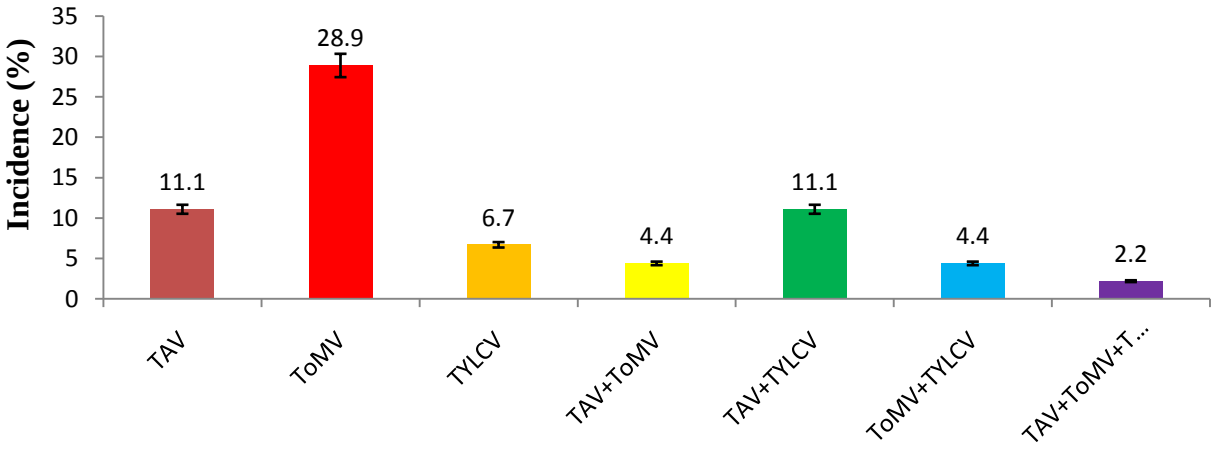
In Talata Mafara Local Government Area, thirty one samples weretested positive out of forty five. ToMV had the highest incidence of 28.9 % followed by TAV and TAV + TYLCV with similar incidence of 11.1 % and then TYLCV (6.7 %). TAV + ToMV and ToMV + TYLCV also detected to have similar incidence of 4.4 % while TAV + ToMV + TYLCV had the least incidence of 2.2 % (Figure 4B).

For BakuraLocal Government Area,out of forty five samples tested, thirty five were positive.ToMV (24.4 %) was detected to have the highest incidence followed by TAV (15.6 %), TYLCV (13.3 %), TAV + TYLCV (11.1 %)and ToMV + TYLCV with 8.9 %.TAV + ToMV and TAV + ToMV + TYLCV had the similar incidence of 2.2 % (Figure 4C).

(A) Tsafe LGA



(B) Talata Mafara LGA



(C) Bakura LGA

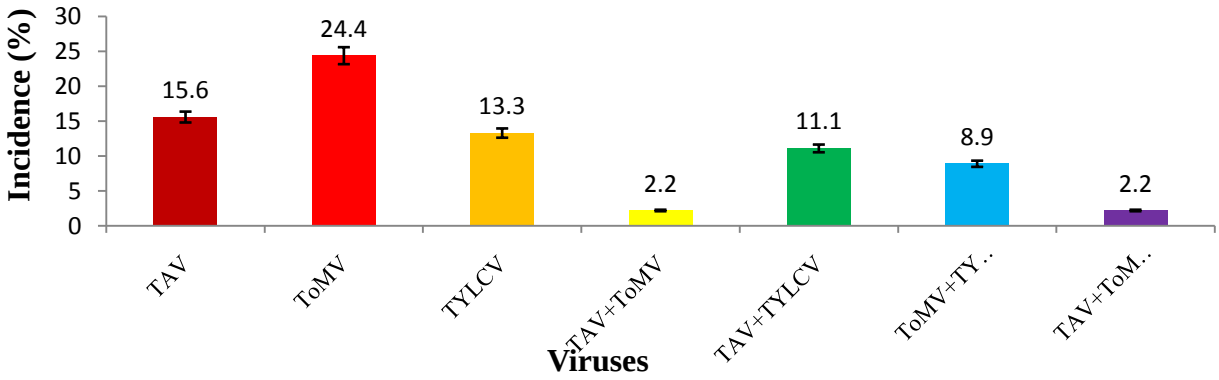


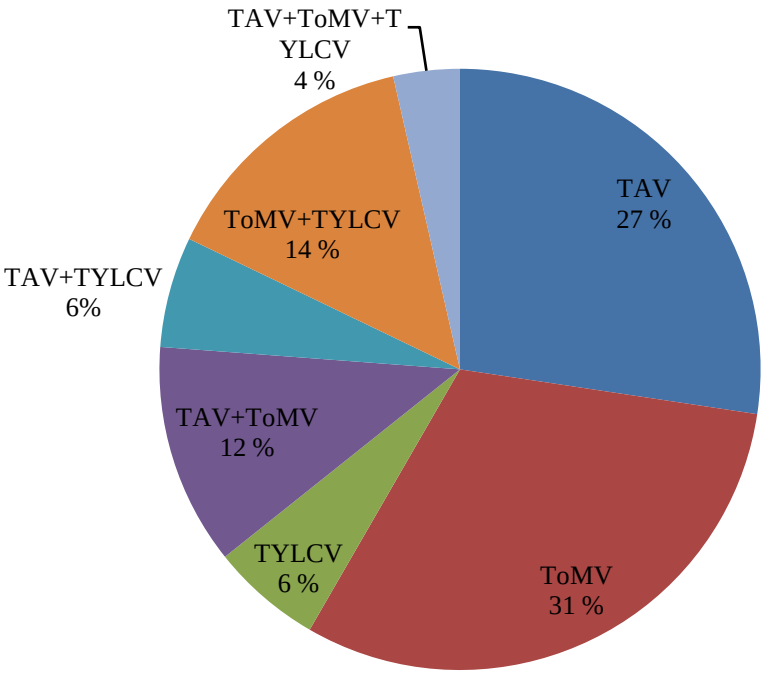
Figure 4: Incidence of tomato viruses in (A)Tsafe (B) Talata Mafara (C) Bakura Local Government Area of Sokoto Stateduring the 2016 dry season.

4.1.3 Occurrenceof viruses of tomato in Sokoto and Zamfara States.

Virusesdetected in Sokoto and Zamfara States were found to occur both singly and in mixture. In Sokoto State, ToMV had the highest occurrence of 31 % followed by TAV with 27 % and mixture of ToMV + TYLCV (14 %). TAV + ToMV was detected to have occurrence of 12 % , TYLCV and TAV + TYLCV had the same occurrence of 6 % while combination of TAV + ToMV + TYLCV had the least occurrence (4 %) as shown in Figure 5A.

In Zamfara State, TAV had the highest occurrence of 28 % followed by ToMV (24 %) and least by TYLCV (16 %), ToMV + TYLCV had the occurrence of 7 %, TAV + ToMV (5 %), TAV + TYLCV had occurrence of 17 % while TAV + ToMV + TYLCV was detected to have the least occurrence (3 %) in the state Figure 5B.

(A) Sokoto State



(b) Zamfara State

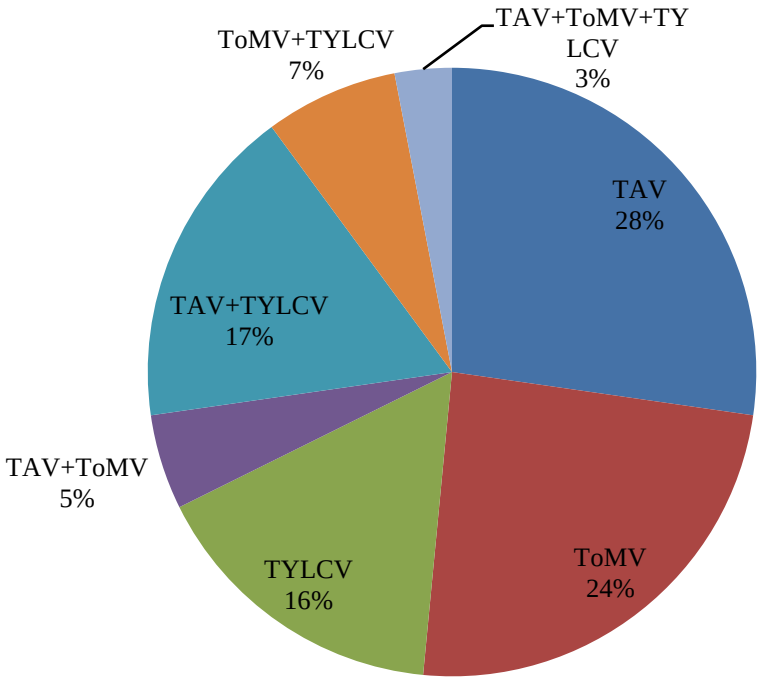


Figure 5: Occurrence of virusesof tomato in(A) Sokoto (B) Zamfara Stateduring the 2016 dry season.

4.1.4 Distribution of Viruses of Tomato in Sokoto and Zamfara States.

Distribution of viruses in Sokoto State (Table 4) did not vary much from one Local Government Areas to another. Three viruses (TAV, ToMV and TYLCV) were detected at all the locations of the three Local Government Areas.

In Zamfara State, TAV, ToMV and TYLCV werealso detected inall the nine locations visited except Dan Amanawar Galadima (Tsafe LGA) where ToMV was not detected (Table 5).Different locations of the viruses detected are shown in Figures 6 and 7 in Sokoto and Zamfara States respectively.

Table 4: Distribution of *Tomato aspermy virus*, *Tomato mosaic virus* and *Tomato yellow leaf curl virus* in three Local Government Areas of Sokoto State, 2016 dry season.

LGA	Location	Number of Samples tested	Tomato Viruses						
			Single infection			Mixed infection			
			TAV	ToMV	TYLCV	TAV, ToMV	TAV, TYLCV	ToMV, TYLCV	TAV, ToMV, TYLCV
Raba	Majiyan Tambari	15	+	6 +	_	+	_	_	_
	Maikujera	15	6 +	3 +	+	_	_	+	_
	Tofa	15	9 +	_	_	2 +	+	3 +	_
Kware	Kiyasa	15	_	5 +	+	2 +	+	3 +	+
	Aguwar lalle	15	2 +	_	+	3 +	2 +	+	_
	Gidan Kwano	15	+	+	_	_	_	_	2+
Tureta	Marna	15	+	2 +	_	+	_	_	_
	Tsamiya	15	+	4 +	_	_	_	+	_
	Magina	15	3 +	5 +	2 +	+	+	3 +	_
Total		135	23	26	6	10	5	12	3

TAV= *Tomato aspermy virus*, ToMV= *Tomato mosaic virus*, TYLCV= *Tomato yellow leaf curl virus*, += Detected, - = Not detected

Table 5: Distribution of *Tomato aspermy virus*, *Tomato mosaic virus* and *Tomato yellow leaf curl virus* in three Local Government Areas of Zamfara State, 2016 dry season.

LGA	Location	Number of Samples tested	Tomato Viruses						
			Single infection			Mixed infection			
			TAV	ToMV	TYLCV	TAV, ToMV	TAV, TYLCV	ToMV, TYLCV	TAV, ToMV, TYLCV
Tsafe	Yankuzo	15	4 +	_	2 +	_	3 +	_	+
	DanAmanawar Galadima	15	9 +	_	2 +	_	2 +	_	_
	Takalawa	15	2 +	_	3 +	2 +	2 +	+	_
Talata Mafara	Tungan Kwate	15	3 +	5 +	+	2 +	2 +	_	+
	Umra	15	2 +	5 +	2 +	_	3+	_	_
	Hura	15	_	3 +	_	_	_	2 +	_
Bakura	Kwana Kalgo	15	3 +	7 +	2 +	+	+	_	_
	Yargeda1	15	+	4 +	+	_	+	+	_
	Yargeda	15	3 +	_	3 +	_	3 +	3 +	+
Total		135	27	24	16	5	17	7	3

TAV= Tomato aspermy virus, ToMV= Tomato mosaic virus, TYLCV= Tomato yellow leaf curl virus, += Detected, - = Not detected.

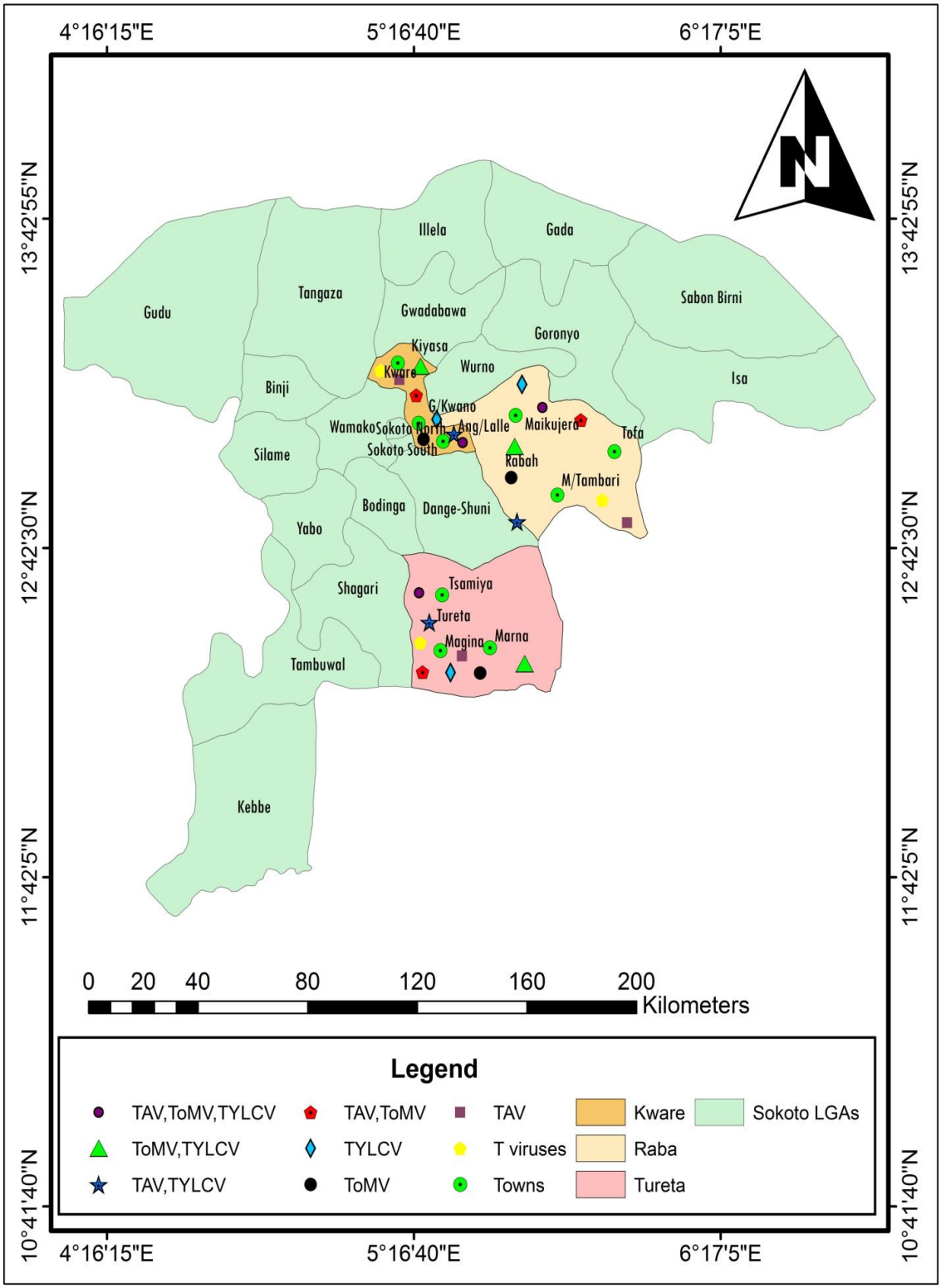


Figure 6: Distribution of TAV, ToMV and TYLCV in SokotoState, 2016 dry season (Source: G I S Geography Laboratory, ABU).

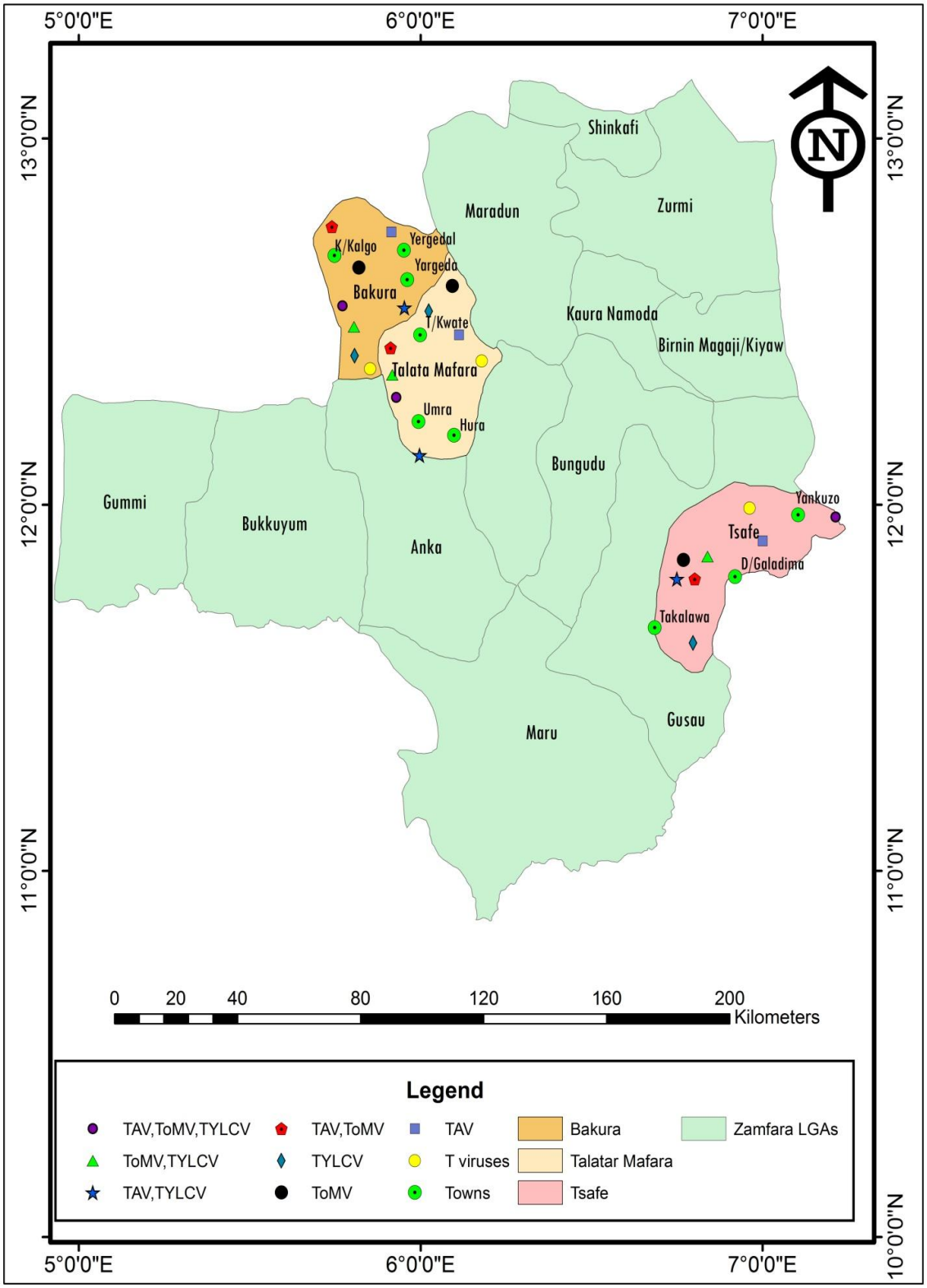


Figure 7: Distribution of TAV, ToMV and TYLCV in Zamfara State, 2016 dry season (Source: G I S Geography Laboratory, ABU).

4.2.Weed Hosts of Viruses of Tomato in Sokoto and Zamfara States during 2016 Dry and Wet Seasons.

Ninety weed samples collected during dry and wet seasons from Sokoto and Zamfara States, belonging to fourteen and thirteen different plant families respectively were tested against TAV, ToMV and TYLCV antisera for the presence of viruses.

In Sokoto State, seven weed species out of forty five samples tested were found to be virus infected in both dry and wet seasons by at least one of the viruses. While in Zamfara State, four weed species out of forty five samples were also detected to be virus infected in both dry and wet seasons by one of the viruses. The ELISA results revealed one weed species (*Ludwigia decurrens* Walter.) from the family *Onagraceae*,as a host of TAV, two weed species (*Thelepogon elegans* L. and *Pennisetum pedicellata* Trin) and one weed species (*Vigna ambasensis* Vigamb.) from the two families (*Poaceae* and *Fabaceae* respectively) as hosts of ToMV and three weed species (*Euphorbia hirta* L., *Physalis peruviana* L. and *Eclipta alba* L.) from three different families (*Euphorbiaceae, Solanaceae and Asteraceae* respectively) as hosts ofTYLCV (Table 6).

In Zamfara State, one weed species (*Phyllanthus amarus* Schum & Thonn.) from the family *Euphorbiaceae* was established as a host of *Tomato aspermy virus* (TAV), two weed species (*Pennisetum pedicellata* Trin. and *Portulaca oleracea* L.) from the two families (*Poaceae and Portulacaceae* respectively)as hosts of *Tomato mosaic virus* (ToMV) and one weed species (*Euphorbia hirta* L.) from the family *Euphorbiaceae* as a hosts of *Tomato yellow leaf curl virus* (TYLCV). The weeds tested and their families in Sokoto and Zamfara states are shown in (Table 7).

Table 6: Weed species tested against antisera of tomato viruses in Sokoto State, 2016 dry and rainy seasons

Families/Weed species	TAV		ToMV		TYLCV	
	Seasons					
	Dry	Wet	Dry	Wet	Dry	Wet
Poaceae						
Thelepogon elegans L.	+	_	+	+	+	_
Elionorus hirtifolius Ridl.	+	NF	_	NF	_	NF
Oryza sativum L.	_	_	_	_	_	_
Axonophus smithii Rydberg.	_	_	+	_	_	_
Pennisetum pedicellata Trin.	_	+	+	+	_	+
Axonophus compressus (Sw.) P.	_	NF	_	NF	_	NF
Imperata cyliderica L.	NF	+	NF	+	NF	_
Fabaceae						
Vigna ambasensis Vigamb.	_	_	+	+	_	+
Arachis hypogeae L.	_	NF	_	NF	_	NF
Sebania sesban (L.) Merr.	_	NF	_	NF	_	NF
Senna tora (L.) Roxb.	NF	_	NF	+	NF	+
Euphorbiaceae						
Acalypha segitalis L.	+	NF	_	NF	+	NF
Caperonia palustris L.	_	NF	_	NF	+	NF
Acalypha hispida L.	+	NF	_	NF	+	NF
Euphorbia hirta L.	+_		_	_	+	+
Chrozophora senegalensis L.	_	NF	_	NF	_	NF
Croton lobaus L.	_NF		_	NF	_	NF
Phyllanthus amarus Schum.	NF	+	NF	+	NF	+

Table 6: Continued

Families/Weed species	TAV		ToMV		TYLCV	
	Seasons					
	Dry	Wet	Dry	Wet	Dry	Wet
Malvaceae						
Pavania oderata Willd.	_	NF	_	NF	_	NF
Abelmoschus esculentus L.	+	NF	+	NF	_	NF
Corchorus olitorius L.	NF	_	NF	+	NF	+
Solanaceae						
Ipomea batatus (L.) Lam.	NF	_	NF	_	NF	_
Physalis peruviana L.	_	+	_	_	+	+
Physalis angulate L.	_	NF	+	NF	+	NF
Asteraceae						
Eclipta alba L.	+	_	_	_	+	+
Ageratum conyzoides L.	_	NF	+	NF	+	NF
Portulacaceae						
Portulaca oleracea L.	_NF		_	NF	_NF	
Amaryllidaceae						
Allium cepa L.	+NF		+	NF	_	NF
Amaranthceae						
Celosia trigyna L.	+	NF	_	NF	+	NF
Amaranthus spinosus L.	NF	_	NF	+	NF+	
Boraginaceae						
Coldenia procumbens Linn.	_	NF	+	NF	_	NF

Table 6: Continued

Families/Weed species	TAV		ToMV		TYLCV	
	Seasons					
	Dry	Wet	Dry	Wet	Dry	Wet
Commelinaceae						
Commelina diffusa Burm. f.	NF	+	NF	_	NF	_
Commelina benghalensis L.	NF	_	NF	+	NF	_
Cyperaceae						
Cyperus rotundus L.	NF	+	NF	+	NF	_
Nyctaginaceae						
Boerhavia diffusa	NF	_	NF	+	NF	+
Onagraceae						
Ludwigia decurrens Walter.	+	+	_	_	+	_
Total	10	5	9	11	11	10

TAV= *Tomato aspermy virus*, ToMV= *Tomato Mosaic virus* and TYLCV = *Tomato yellow leaf curl virus*, += detected positive, NF= weeds not found during surveys.

Table 7: Weed Species Tested Against Antisera of Viruses Infecting Tomato in Zamfara State of Nigeria During 2016 Dry and Wet Seasons.

Families/Weed species	TAV		ToMV		TYLC	
	Seasons					
	Dry	Wet	Dry	Wet	Dry	Wet
Poaceae						
Thelepogon elegans L.	+	_	+	_	_	+
Digitaria horizontalis Willd.	_	_	_	+	_	+
Axonophus smithii Rydberg.	_	_	_	_	NF	+
Elionorus hirtifolium Rydl.	_	NF	+	NF	_	NF
Elionorus elegans Kunth.	_	NF	_	NF	_	NF
*Sorghum bicolor*L.	_	_	+	_	_	+
Cynodon doctylon L.	+	NF	+	NF	_	NF
Oryza sativum L.	_	_	_	_	_	_
Pennisetum pedicellata Trin.	_	_	+	+	_	_
Fabaceae						
Vigna unguiculata (L.) Walp.	+	_	_	_	_	_
Vigna racemosa Hutch & Dalziel.	_	NF	+	NF	_	NF
Crotaralia quinquefolia L.	_	NF	_	NF	_	NF
Senna tora (L.) Roxb.	NF	_	NF	_	NF	+
Rubiaceae						
Mitracarpus scabar Zucc.	_	NF	_	NF	+NF	
Spermacoca ocymoids L.	NF	+	NF	_	NF	_

Table 7: Continued

Families/Weed species	TAV		ToMV		TYLCV	
	Seasons					
	Dry	Wet	Dry	Wet	Dry	Wet
Malvaceae						
Hibiscus surattensis L.	+	NF	_	NF	_	NF
Hibiscus subdariffa L.	NF	_	NF	_	NF	_
Urena lobata L.	_	NF	+	NF	_	NF
Corchorus olitorius L.	NF	_	NF	_	NF	+
Melochia corchorifolius L.	NF	_	NF	_	NF	+
Amaranthceae						
Celosia trigyna L.	+	NF	_	NF	_	NF
Gomphrena celosiodes L.	_	NF	+	NF	+	NF
Amaranthus hybridus L.	+	_	_	_	+	_
Chenopodiaceae						
Chenopodium ambroioides L.	+	NF	_	NF	_	NF
Lamiaceae						
Leucas martinicensis (Jacq.) R. Br.	+	NF	_	NF	+	NF
Euphorbiaceae						
Areurites montana Lour.	+	NF	_	NF	+	NF
Acalypha ciliata Forssk.	_	NF	+	NF	_	NF
Chrozophora senegalensis Lam.	+	_	_	_	_	_
Euphorbia hirta L.	_	+	+	_	+	+
Phyllanthus amarus Schum.	+	+	+	_	_	+

Table 7: Continued

Families/Weed species	TAV		ToMV		TYLCV	
	Seasons					
	Dry	Wet	Dry	Wet	Dry	Wet
Cyperaceae						
Cyperus rotundus L.	NF	+	NF	+	NF	+
Nyctaginaceae						
Boerhavia diffusa	NF	_	NF	_	NF	_
Onagraceae						
Ludwigia decurrens Walter.	+	NF	_	NF	+	NF
Portulacaceae						
Portulaca oleracea L.	_	_	+	+	+	_
Molluginaceae						
Mollugo nudicaulis Lam.	+	NF	+NF		_	NF
Total	13	3	13	3	10	10

TAV= *Tomato aspermy virus*, ToMV= *Tomato Mosaic virus* and TYLCV = *Tomato yellow leaf curl virus*, += detected positive, NF=weeds not found during surveys.

CHAPTER FIVE

5.0 DISCUSSION

The incidence, distribution and alternative hosts of threetomato viruses (*Tomato aspermy virus, Tomato mosaic virus* and *Tomato yellow leaf curl virus*) in Sokoto and Zamfara states were examined in this study.The symptoms observed on the samples, which included leaf curl, mosaic, mottling, distortion, stunting, chlorosis, and necrosis where the viruses were detected have been reported to be incited by the viruses (Gallitelli, 2000). Leaf curl, mosaic and mottling symptoms were very pronounced on most of the samples. These symptoms have been observed on tomato infected by these viruses (Breman, 1989; Blencowe and Caldwell, 1994; Ssekyewa, 2006;Alegbejo, 2015). The serological test conducted accurately affirmed that the causal agents of the aforementioned symptoms were the viruses. Some of the samples tested had virus-like symptoms, but no virus was detected using the serological method employed in this research. These symptoms could have been caused by other viruses whose antisera were unavailable for use in this study. Green (1991) reported about 146 viruses from tomato. These virus-like symptoms could be due to reasons other than virus infection such as abiotic factors which incite the virus-like symptoms (Alireza *et al*., 2012; Hull, 2002).

From the results, it was found that TAV, ToMV and TYLCV were detected in Raba, Kware and Tureta Local Government Areas of Sokoto State and Tsafe, Talata Mafara and Bakura Local Government Areas of Zamfara State. This could be as a result of proximity of tomato farms to other fields. Mzyad *et el*. (1994) found that adjacent field of vegetables and other field crops present at tomato planting played a big role in harbouring vectors, which eventually infested tomato. Members of the families

Poaceae, Fabaceae, Euphorbiaceae, Asteraceae, Malvaceae, Solanaceae, Portulacaceae, Amaranthaceae, Chenopodiaceae, Lamiaceae, Molluginaceae, Rubiaceae and Onagraceae were reported to be major hosts of tomato viruses (Kashina *et al*.,2002; Alegbejo and Banwo, 2005;Khan *et al*., 2013; Alegbejo,2015). Early work by Czosnek and Laterrot (1997) and recently by Alegbejo (2015) had reported more than ten viruses of tomato in Nigeria. Ssekyewa (2006) also detected eight viruses of tomato in Uganda.

Tomato aspermy virus was detected in all the six Local Government Areas of the two States but found to be highest in Raba and Tsafe local government areas of Sokoto and Zamfara respectively.From the available literature, this is the first report of TAV in the study areas (Sokoto and Zamfara states).Similar finding was reported by Thomson (1962) where Tomato aspermy virus was first isolated in 1960 from an outdoor tomato plantgrowing near Christchurch in New Zealand.Kuti and Molline (1984) isolated a mild strain of TAV from tomato in Maryland. The virus also has been isolated in Australia as reported by Megan *et al*. (1996). This confirmed what was reported by Kaper and Waterworth (1981) and Shi *et al*. (1993) that TAV as an important agent of Chryasanthemum disease and occurs worldwide. It has also been reported to be isolated from Chrysanthemum, in which it caused severe flower break or distortion (Hollings and Stone, 1971). Habili and Franki (1974) reported Tomato aspermy virus to be less extensively studied among cucumovirus.

Tomato mosaic virus was detected in the two States.The incidence was higher in Kware and Tureta than Raba LGA of Sokoto state while higher incidence was recorded at Talata Mafara and Bakura than Tsafe LGA of Zamfara state.This could

have been due to its being seed-borne (Brunt *et al*., 1990) and also due to the fact that most farmers extract their own seed from previous season for subsequent cropping cycles. The survey conducted showed that in Dan Amanawar Galadima of Tsafe Local Government Area of Zamfara State, where farmers sourced their seed from Seed Company, ToMV did not occur there (Appendix V). Similar finding was reported byArogundede *et al*. (2007) in their earlier research conducted at Teaching and Research Farm of the University, Ilorin,Nigeria. Furthermore, Simons and Sobulo(1975) reportedToMV to be one of the most important virus diseases of tomato in Nigeria. Khan (1997) detectedToMV in Pakistan. Brunt *et al*.(1990) reported that ToMV was seed born. This could explain the high incidence ofthe virus. This is more so when farmers in Tureta and Talata Mafara LGAs used seeds obtained from previous cropping. ToMV has been found as an aerosol in fog in USA (Castello et al., 1995) and in nutrient solution used for crop cultivation in Apulia, Italy (Gallitelli *et al*., 1982; Pares *et al*., 1992), and in Spain (Cordero, 1983). It has also been reported in Tanzania, Malawi and Zambia (AVRDC, 1987 and 1993; Nono-Womdim, 1994).Eraslan *et al*. (2007) reported that ToMV provokes a serious disease in tomato plant especially in yield of infected susceptible cultivars.

*Tomato yellow leaf curl virus*is distributed worldwide. It has been reported in Nigeria by Lana and Wilson (1976), Czosnek and Laterot (1997) and Alegbejo (1995, 2015) and many African countries such as Sudan (Yassin and Nour, 1965; Yassin, 1975), Tunisia (Cherif and Russo, 1983), Zambia (Nono-Womdim, 2004), Kenya (Nono-Womdim, 2004), Uganda (Nono-Womdim, 2004; Ssekyewa, 2006), Tanzania (Kashina *et al*., 2002b), Cameroon (Czosnek and Laterot, 1997) and Burkina Faso (Konate *et al*., 1995). Similar explanation could be attributed to the occurrence of

TYLCV in all the six Local Government Areas of Sokoto and Zamfara States. The occurrence observed in the two states could be as a result of no weeded or poorly weeded fields as well as field that were surrounded by virus host plants (Appendices III and V).

A wide range of weeds and other crops were observed in both tomato field and surrounding farms. Studies by Kashina *et al*. (2002a) and Alegbejo (2015) revealed that most weeds and other cultivated crops served as reservoir hosts to tomato viruses. In this study, it was established that weeds could actas alternative hosts to some tomato viruses that were identified during this study. In Sokoto State, seven weed species out of forty five samples tested were detected positive in both dry and wet seasons for one of the viruses. While in Zamfara State, four weed species out of forty five samples tested were detected positive in both dry and wet seasons for one of the viruses.The complex nature of the agro-ecosystem within which a majority of tomato farmers work require holistic approach for future studying of tomato viruses' pathosystem (Andeson and Morales, 2005). Most of the farmers contacted during the survey were smallholder farmers (0.04 – 1.06 ha) as shown in appendices II and IV. They tried avoiding risks related to farming by growing multiple crops, which probably contributed to higher incidence of the viruses. Tomato viruses infected cultivated crops from several sources such as weeds and seeds (Appendices III and V). In Sokoto State, seven weed species out of forty five samples tested were detected positive in both dry and wet seasons for one of the viruses. While in Zamfara State, four weed species out of forty five samples tested were detected positive in both dry and wet seasons for one of the viruses.

In Sokoto state, TAV infected one weed species (*Ludwigia decurrens*Walter.) from the family *Onagraceae*in both during dry and wet seasons respectively. TAV was not detected from any species of family *Fabaceae*in Sokoto state. In Zamfara, TAV infected also one weed species (*Phyllanthus amarus* Schum & Thonn.) from the family *Euphorbiaceae*. This is in line with what was established by Brunt *et al*. (1996) where they reported different plant species to serve as host rangeof TAV. To the best of my knowledge, this is the first report of TAV detected from *Ludwigia decurrens* Walter. and *Phyllanthus amarus* Schum & Thonn. in Sokoto and Zamfara states respectively.

Surveys in Sokoto showed that ToMV infected twoweed species (*Thelepogon elegans* L. and*Pennisetum pedicellata* Trin)and one weed species (*Vigna ambasensis*Vigamb.) from the two families (Poaceae and *Fabaceae*respectively)while inZamfara, ToMV was detected in two weed species (*Pennisetum pedicellata* Trin. and *Portulaca oleracea*L.) from the two families (*Poaceae and Portulacaceae* respectively). The detection of ToMV from aforementioned plant species and their families confirmed what was reported by John *et al*. (1999) that the virus is very stable with wide host range.

In Sokoto state, TYLCV infected three weed species (*Euphorbia hirta* L., *Physalis peruviana* L. and *Eclipta alba* L.) from three different families (*Euphorbiaceae, Asteraceae and Solanaceae*respectively) while in Zamfara, TYLCV infected one weed species (*Euphorbia hirta* L.) from the family *Euphorbiaceae*. Papayiannis *et al*. (2011) reported that though, TYLCV is a primarilya virus of tomato, it has wide host range

and infect many species which include cultivated and uncultivated plant species belonging to different families.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

Tomato aspermy virus, *Tomato mosaic virus* and *Tomato yellow leaf curl virus* were detected in all the three Local Government Areas each of the two States (Sokoto and Zamfara) either singly or in mixed infections. In Sokoto state, one weed species (*Ludwigia decurrens* Walter.) from the family *Onagraceae*,detected as a host of *Tomato aspermy virus* (TAV), two weed species (*Thelepogon elegans* L. and *Pennisetum pedicellata* Trin) and one weed species (*Vigna ambasensis* Vigamb.) from the two families (Poaceae and *Fabaceae* respectively) as hosts of *Tomato mosaic virus* (ToMV) and three weed species (*Euphorbia hirta* L., *Physalis peruviana* L. and *Eclipta alba* L.) from three different families (*Euphorbiaceae, Asteraceae and Solanaceae* respectively) as hosts of *Tomato yellow leaf curl virus* (TYLCV). In Zamfara State, one weed species (*Phyllanthus amarus* Schum & Thonn.) from the family *Euphorbiaceae* detected as a host of *Tomato aspermy virus* (TAV), two weed species (*Pennisetum pedicellata* Trin. and *Portulaca oleracea* L.) from the two families (*Poaceae and Portulacaceae* respectively)as hosts of *Tomato mosaic virus* (ToMV) and one weed species (*Euphorbia hirta* L.) from the family *Euphorbiaceae* as a hosts of *Tomato yellow leaf curl virus* (TYLCV).

6.2 Conclusion

1) TAV, ToMV and TYLCV occurred singly and in mixed infections in tomato plant in Sokoto and Zamfara States of Nigeria.

2) TAV was detected for the first time in Sokoto and Zamfara States of Nigeria.

3) It was found that *Ludwigia decurrens* Walter acted as alternative host for TAV, *Thelepogon elegans* L., and *Vigna ambasensis* Vigamb for ToMV, *Physalis peruviana* L. and *Eclipta alba* L. for TYLCV in Sokoto while *Phyllanthus amarus* Schum & Thonn.acted as alternative host ofTAV,*Portulaca oleracea* L. for ToMV in Zamfara State. *Pennisetum pedicellata* Trin. and *Euphorbia hirta* L. were found to be alternative hosts for ToMV and TYLCV in Sokoto and Zamfara States respectively.

6.3 Recommendations

1) Farmers should employ regular weeding mechanisms to avoid weeds build up that harbour *Tomato aspermy virus,Tomato mosaic virus* and *Tomato yellow leaf curl virus* in both dry and wet seasons.

2) Tomato varieties should be developed with multiple resistances to the three viruses.

3) Molecular techniques should be employed to determine the strains and relatedness between TLCV and TYLCV in the study areas.

4) Studies should be conducted on the epidemiology of these viruses in order to develop integrated management strategies for them.

REFERENCES

Adekiya, A. O., Agbede, T. M. and Ojomo, A. O. (2009). Effects of tillage methods on soil properties, nutrient content, growth and yield of tomato on an alfisol of Southwestern Nigeria. *American-Eurasian Journal of Sustainable Agriculture* 3(3): 348-353.

Adenuga, A. H., Muhammad, L. A., and Rotimi O. A. (2013). Economics and Technical Efficiency of dry season tomato production in selected areas in Kwara State, Nigeria. *Agris on-line Papers in Economics and Informatics* 5 (1): 11-19.

.

Agrios, G. N. (2005). *Plant Pathology*. Fifth edition, London Academic Press. 757-788 pp..

Alegbejo, M. D. (2015). *Virus and virus-like diseases of crops in Nigeria*. Zaria Ahmadu Bello University Press. 202-203pp.

Alegbejo, M. D. (1995). Screening of tomato accessions for resistance to leaf curl virus. *Journal of Agricultural Technology* 3: 65–68

Alegbejo, M. D. and Banwo, O. O. (2005). Host plants of *Bemisia tabaci* Genn. in Northern Nigeria. *Journal of Plant Protection Research* 45 (2): 93-98.

Alegbejo, M. D. and Ogunlana, M. O. (1995). Assessment of losses in tomato caused by *Tomato leaf curl virus*. Abstract of papers presented at the 24 annual conference of the NSPP, held at the National Root Crops Research Institute (NCRI) Umudike, 28–31 May 1995, p. 27.

Alegbejo, M. D. and Uvah, I. I. (1987). Effect of intercropping pepper with tall companion crops on the Incidence of *Pepper veinal mottle virus* on pepper. *Nigerian Journal of Entomology* 7:82-87.

Alireza, M. H., Fereidoon, A., Babak, A. M. and Mina, G. (2012). Natural incidence of tomato viruses in the North of Iran. *Phytopathologia Mediterranea* 51 (2): 390−396.

Amans, E. B., Shebayan, J. A. Y. and Miko, S. (2008). The influence of mulch and plant density on the production of irrigated tomato (*Lycopersicon esculentum* Mill) under conditions of high water table at Kadawa. *Paper presented at the 26th annual conference of the Horticultural Society of Nigeria, Mubi, Adamawa State*, 26 – 30th October, 2008.

Anang, B. T., Zulkarnain, Z. A. and Yusif, S. (2013). Production constraints and measures to enhance the competitiveness of the tomato industry in Wenchi municipal District of Ghana. *American Journal of Experimental Agriculture* 3(4): 824-838.

Anderson P. K., and Morales F. J.(2005). Whitefly and Whitefly-borne Viruses in the Tropics: Building a Knowledge base for Global Action. pp.158-159.

Anonymous. (2000). Growing Tomatoes in Nigeria. *Commercial Crop Guide Series*. United States Agency for International Development; USAID and Information communication for Agricultural Growth I Nigeria pp1-4.

Arab, L. and Steck, S. (2000). "Lycopene and cardiovascular disease." *American Journal of Clinical Nutrition* 71: 1691–1695.

Arogundade, O., Balogun, O. S. and Fawole, O. B.(2007). Incidence and severity of common viral and fungal diseases of dry season tomato crop in a Southern Guinea Savannah Agro-ecology.*Agrosearch* 9:53 – 60

Atiri, G. I. (1986). A disease of fluted pumpkin (*Telfairia occidentalis)* caused by a yellow vein clearing strain of pepper veinal mottle virus in Nigeria. *Journal of Plant Protection* 3: 105-110.

Averre, C. W. and Gooding, G. V. (2000). Virus diseases of greenhouse tomato and their management. Vegetable disease Information Note 15 (VDIN- 0015. Plant Pathology Extension. North Carolina State University.

Ayandiji, A, O. R. and Adeniyi Omidiji, D. (2011). Determinant post-harvest losses among tomato farmers in Imeko-Afon Local Government Area of Ogun State, Nigeria. *Global Journal of Science Frontier Research*11 (5): 22-28.

AVRDC, (1994). AVRDC Progress Report, 1993. Asian Vegetable Development Centre, Shanhua, Taiwan (ROC). 153 pp.

AVRDC, (1987). AVRDC Progress Report, 1987. Asian Vegetable Development Centre, Shanhua, Taiwan (ROC). 142 pp.

Bai, Y. and Lindhout, P. (2007). Domestication and breeding of tomatoes: what have we gained and what can we gain in the future? *Annals of Botany* 100:1085–1094.

Basu, A. and Imrhan, V. (2007). Tomatoes versus lycopene in oxidative stress and carcinogenesis: conclusions from clinical trials. *European Journal of Clinical Nutrtion* 61 (3): 295-303.

Beckles, D. M. (2012). Review: Factors affecting the postharvest soluble solids and sugar content of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biology and Technology* 63 (1): 129–140.

Blencowe, J. W. and Caldwell, J. (1994). Aspermy-a new virus didease of tomato. *Annals of Applied Biology* 36: 320-326.

Bock, K. R. (1982). The Identification and partial charaterisation of plant viruses in the tropics. *Tropical Pest Management* 28 (4): 399-411.

Bodunde, J. G. (2003). Seasonal variation effects on flower formation and fruit set in tomato (*Lycopersicon esculentum* Mill.). *ASSET Journal, series A*3: 69-77.

Borguini, R. and Torres, E. (2009). Tomatoes and tomato products as dietary sources of antioxidants. *Food Review International* 25: 313–325.

Breman, L. L., (1989). Tomato mosaic virus. *Plant Pathology Circular* No. 322.

Brown, J. K. (1994). Current status of *Bemisi tabaci* as a pest and virus vector in agroecosystems worldwide. *Plant Protection Bulletin* 42: 3–32.

Brunt, A. A., Crabtree, K., Dallwitz, M. J., Gibbs, A. J., Watson, L. and Zurcher, E. J. (1996). Plant Viruses Online: Descriptions and lists from VIDE Database. CAB International, Wallingford, UK, 1484 pp.

Brunt, A., Grabtree, K. and Gibbs, A. (1990). *Viruses of tropical plants*. CAB International. UK. 707 pp.

Brunt, A. A., Kenten, R. H. and Phillips, S. (1978). Symptomatologically distinct strains of Pepper veinal mottle virus from four (4) West African Solanaceous crops. *Annals of Applied Biology* 88: 115-119.

Buchen, O. C. (2003). Tospovirus. International Committee on Taxonomy of Viruses-Data Base (ICTVdB). Nueva York.

Butter, M. S. and Rataul, H. S. (1977). The virus-vector relationship of the tomato leaf curl virus (TLCV) and its vector *Bemisia tabaci* Gennadius (*Homoptera: Aleyrodidae*). *Phytoparasita* 5: 173–180.

Cano, A., Acosta, M. and Arnao, M. (2003). Hydrophilic and lipophilic antioxidant activity changes during on-vine ripening of tomatoes (*Lycopersicon esculentum* Mill). *Postharvest Biology and Technology* 28: 59–65.

Castello, J. D., Lakshman, D. K., Tavantzis, S. M., Rogers, S. O., Bachand, G. D., Jagels, R., Carlisle, J., and Liu, Y. (1995). Detection of infectious Tomato mosaic virus in fog and clouds. *Phytopathology* 85: 1409 - 1412.

Chaube, H. S. and Pundhir, V. S. (2005). *Crop Diseases and their Management*. Prentice Hall of India Private Limited. 724p.

Cherif, C. and Russo, M. (1983). Cytological evidence of the association of a geminivirus with the tomato yellow leaf curl disease in Tunisia. *Phytopathologische Zeitschrift* 108: 221-225.

Chidi, A. (2012). Tomato, nutritious vegetable. Seventeen Nigerian Economic Summit. *Manufacturing today Nigeria*. African post web team. Pp1-3.

Chiemsombat, P., Murayama, A. and Ikegami, M. (1991). *Tomato yellow leaf curl virus* in Thailand and Tobacco leaf curl virus in Japan are serologically identical. *Annals of Phytopathological Society of Japan* 57: 595 - 597.

Clark, M. F. and Adams. A. N. (1977). Characteristics of the microplate method of enzyme-linked immunosorbent assay for the detection of plant viruses. *Journal of General Virology* 34: 475-483.

Clinton, S. K. (1998). Lycopene; chemistry, biology and implications for human health and diseases. *Nutrition* 56: 35–51.

Cohen, S. and Antignus, Y. (1994). Tomato yellow leaf curl virus (TYLCV), a whitefly-borne geminivirus of tomatoes. In: Harris K.F. (ed.): *Advances in Disease Vector Research*. Springer-Verlag, New York10: 259–288.

Cohen, S. and Nitzany, F. E. (1966). Transmission and host range of the *Tomato yellow leaf curl virus*. *Phytopathology* 56: 1127 - 1131.

Cordero, M., and Gaborjanyi, R. (1983). Study of interrelationship between TEV and TMV viruses in tomato plants. *Agrotecnia - de Cuba* 15: 101 - 111.

Credi, R., Betti, L. and Canova, A. (1989). Association of a geminivirus with a severe disease of tomato in Sicily. *Phytopathological Medit* 28: 223 - 226..

Czosnek, H., Ber, R., Navot, N., Zamir, D., Antignus, Y. and Cohen, S. (1988). Detection of *Tomato leaf curl virus* in lysates of plants and insects by hybridization with a viral DNA probe. *Plant Disease* 72: 949 - 951.

D'Arcy WG (1972) Solanaceae studies II: typification of subdivisions of Solanum. *Annals of Molecular Botany* 59:262– 278.

Dafalla, G. A. (2004). Situation of tomato and pepper viruses in Africa. International Institute of Tropical Agriculture (IITA).

Delatte, H., Dalmon, A., Rist, D., Soust-rade, I., Wuster, G., Lett, J. M., Goldbach, R. W., Peterschmitt, M. and Reynaud, B. (2003). *Tomato yellow leaf curlvirus* can be acquired and transmitted by *Bemisia tabaci* (Gennadius) from Tomato fruit. *Plant Disease* 87: 1297-1300.

Denton, O. A. and Swarup, V. (1983), Tomato cultivation and its potential in Nigeria. *Acta Horticulturae* 123: 257-263.

De Bokx, J. A. and Huttinga, H. (1981). Potato virus Y. CMI/ AAB. *Descriptions of Plant Viruses*, no. 242.

Di Mascio, P., Kaiser, S. and Sies, H. (1989). Lycopene as the most efficient biological carotenoid singlet Oxygen quencher. *Archives of Biochemistry and Biophysics* 274 (2): 532-538.

Douglas, S. M. (2005). Powdery mildew of tomato. Department of Plant Pathology and Ecology. The Connecticut Agricultural Experimental Station.

Duncan, J. M. and Torrrance, L. (1992). Techniques for the rapid detection of plant pathogens. Blackwell Scientific Publications. FAO, 1989, Production Year Book, Vol. 43.

Eraslan, F., B. Akbas, A. Inal and C. Tarakcioglu. (2007). Effects of foliar sprayed calcium sources on Tomato mosaic virus (ToMV) infection in tomato plants grown in greenhouses. *Phytoparasitology* 35 (2): 150-158.

Fajinmi, A. A. (2006). The incidence, spread and possible control strategies of *Pepper veinal mottle virus (*PVMV) disease on pepper (*Capsicum annuum*.L.) in Nigeria. Ph. D thesis University of Ibadan Oyo State Nigeria.

FAOSTAT. (2014). Global tomato production in 2012. Rome, FAO.

Fauquet, C. M., Bisaro, D. M., Briddon, R. W., Brown, J. K., Harrison, B. D., Rybicki, E. P. Stenger, D. C. and Stanley, J. (2003). Revision of taxonomic criteria for species demarcation in the family *Geminiviridae*, and an updated list of *Begomovirus* species. *Archives of Virology* 148: 405 – 421.

Fauquet, M. C. and Mayo, M. A. (1999). Abbreviations for plant virus names. *Archives of Virology* 144: 6.

Food and Agricultural Organization. (2010). FAO production year Book, Rome.

Food and Agriculture Organization. (2008). Basic Harvest and Post-harvest Handling Considerations for Fresh Fruits and Vegetables. Postharvest Training on Food Processing/FAO manual food handling and preservation/CHAPTER 2. FAO, Rome.

Foolad, M. R. (2007). Genome mapping and molecular breeding of tomato. *International Journal of Plant Genomics* 64358: 52. doi:10.1155/2007/64358.

Freeman, B. B. and Reimers, K. (2010). Tomato consumption and health: emerging benefits. *American Journal of Lifestyle Medicine*8:1-11.

Friedmann, M., Lapidot, M., Cohen, S., Pilowsky, M. (2002). Novel source of resistance to Tomato yellow leaf curl virus exhibiting a symptomless reaction to viral infection. *Journal of the American Society for Horticultural Science* 123: 1004–1007.

Gallitelli, D. (2000). The ecology of Cucumber mosaic virus and sustainable agriculture. *Virus Research* 71: 9 – 21.

Gallitelli, D., Savino, V., and Piazzolla, P (1982). Mixed infections of Tobacco necrosis virus and Potato Virus Y in tomato, Apulia, Italy. *Informatore - Fitopatologico* 32: 43 - 45.

Garvey, T. and Hewitt, J. (1991). Starch and sugar accumulation in twoaccessions of

Gerling, D. and Mayer, T. (1995). *Bemisia*: 1995 Taxonomy, Biology, Damage, Control and Management, pp. 93 - 288.

Ghanim, M., Sobol, I., Ghanim, M. and Czosnek, H. (2007). Horizontal transmission of begomoviruses between *Bemisia tabaci* biotypes. *Arthropod-Plant Interactions* 1: 195-204.

Giovannucci, E. (2002). Tomatoes, tomato-based products, Lycopene, and cancer: Review of the epidemiologic literature." *Journal of the National Cancer Institute*91(4): 317-331.

Giovannucci, E., Rimm, E. B., Liu, Y., Stampfer, M. J. and Willett, W. C. (2002). A prospective study of tomato products, lycopene, and prostate cancer risk. *Journal of the National Cancer Institute* 94: 391–398.

Green, S. K. 1991. Guidelines for diagnostic work in plant Virology. AVRDC Tech. Bull. No. 15. 63 pp.

Greer, L. and Dole, J. M. (2003). Aluminium foil, aluminium-painted, plastic, and degradable mulches increase yield and decrease insect-vectored viral diseases of vegetables. *Horticultural technology* 13: 276-284.

Groth, J. V., Ozmon, E. A. and Busch, R. H. (1999). Repeatability and relationship of incidence and severity measures of scab of wheat caused by *Fusarium graminearum* in inoculated nurseries. *Plant Disease83*: 1033 -1038.

Habili, N. and FranckI, R. I. B. (1974). Comparative studies on tomato aspermy and cucumber mosaic viruses. I. Physical and chemical properties. *Virology* 57: 392-401.

Hanna, H. Y. and Adams A. J. (1982). Increased yield in slicing cucumbers with vertical training of plants and reduced plant spacing. *Horticulture* 22: 32-34.

Harrison, B. D., Muniyappa, V., Swanson, M. M., Roberts, I. M. and Robinson, D. J. (1991). Recognition and differentiation of seven whitefly-transmitted geminiviruses from India, and their relationships to *African cassava mosaic virus* and Thailand mungbean yellow mosaic viruses. *Annals of Applied Biology* 118: 299 - 308.

Harrison, B. D., Finch, J. T, Gibbs, A. J., Hollings, M., Shepherd, R. J., Valenta, V. and Wetter C. (1971). Sixteen groups of plant viruses. *Virology* 45: 356-363.

Hilje, L., Costa, H. S., and Stansly, P. A. (2001). Cultural practices for managing Bemisia tabaci and associated viral diseases. *Crop Protection* 20: 801-812.

Hill, D. S. and Waller, J. M. (1990). Pests and diseases of tropical crops. Longman Scientific and Technical, U.S.A. *Plant Disease* 79: 360-369.

Hollings, M. and Huttinga, H. (1976). *Tomato mosaic virus*, Descriptions of plant viruses. Commonwealth. Mycoll. *International Association of Applied Biology* England. 156p.

Hollings, M. and Stone, O. M. (1971). Tomato aspermy virus. Description of plant viruses. Commonwealth. Mycoll. *International Association of Applied Biology*.,kew, Survey, England. No. 79.

Horvath, J. and Nienhaus, F. (1982). Separation of viruses from inhibitor containing pepper leaf extracts (*Capsicum annuum L.* L.) with controlled pore glass exclusion Chromatography. *Acta Phytopathology Academic Science Hung* 17: 41-45.

Huguenot, C., Furneaux, M. T., Clare, J. and Hamilton, R. I. (1997). Sero-diagnosis of Pepper veinal mottle virus in West Africa using specific monoclonal antibodies in DAS-ELISA. *Journal of Phytopathology* 144: 29-32.

Hull, R. (2002). *Matthew's plant virology*. (4th edition).London: Academic Press. 1001pp.

Hunter, J. Jr, Pittenger, D. and Voss, R. (1991). *Saving Water in Vegetable Gardens.* Vegetable Research and Information Center, University of California. pp1-3.

ICTVdB Management (2006a). 00.029.0.03.043. *Tomato yellow leaf curl viru*s. In: ICTVdB - The Universal Virus Database, version 4. Büchen-Osmond, C. (Ed), Columbia University, New York, USA

ICTVdB Management. (2006b). 00.071.0.01.013. *Tomato mosaic virus.* In: ICTVdB – The Universal Virus Database, version 4. Büchen-Osmond, C. (Ed), Columbia University, New York, USA.

ICTVdB Management, (2006c). 00.057.0.01.052. *Pepper veinal mottle virus*. In: *ICTVdB– The Universal Virus Database*, version 4. Büchen-Osmond, C. (Ed), Columbia University, New York, USA.

ICTVdB version 2. (1995-1999d). 57.0.1.0.058 *Potato virus Y*. The taxonomy of version 2 is based on the 6th ICTV Report.

Innes, E. (2014). How eating tomatoes could increase male fertility: Key compound in the fruit could boost sperm count by 70%. Australia Daily Mail. Retrieved from http://www.dailymail.co.uk/health/article-2620676.

International Committee on Taxonomy of Viruses (ICTV). (2012). Virus taxonomy, 2009 release. ICTVdB Management (2006). 00.010.0.04.001. Cucumber mosaic virus. In: ICTVdB - The Universal Virus Database, version 4. Büchen-Osmond, C. (Ed), Columbia University, New York, USA.

Jane, E., Polston, J. E. and Lapidot, M. (2007). Management of tomato yellow leaf curl virus: US and Israel perspectives.*H. Czosnek (ed.), Tomato Yellow Leaf Curl Virus Disease* P 251–262.

John, D., Castello S., Rogers, O., William, T., Starmer Catharine, M., Catranis Lijun Ma George, D., Bachand Yinghao Zhao J. and Smith, E. (1999). Detection of tomato mosaictobamovirus RNA in ancient glacial ice. *Polar Biology* 22: 207-212.

Jones, J. B., R.E. Stall and T.A. Zitter. (1991). *Compendium of tomato diseases*. St. Paul. APS Press. 75 p.

Kameya-Iwaki, M., Murakami, K., Ito, S., Hanada, K. and Tanaka, S. (2000). Semi-persistency of *Myzus persicae* transmission of cucumoviruses systemically infecting leguminous plants. *Journal of General Plant Pathology Tokyo* 66 (1): 64-67.

Kang, K. Y., J. K. Suh and I. C. Yu. (1981). Identification of viruses isolated from tomatoes and survey on the occurrence of virus diseases of tomatoes. The Research reports of the Office of Rural Development (Korea R.). *Horticultural Series* 23: 10-17.

Kaper, J. M. and Waterworth, H. E. (1981). Cucumoviruses. In: *Handbook of Plant Virus Infections and Comparative Diagnosis*, pp. 257-331. Edited byE. Kurstak. Elsevier : North-Holland Biomedical Press.

Kashina, B. D., Mabagala, R. B. and Mpunami, A. A. (2002a). Reservoir weed hosts of *Tomato yellow leaf curlbegomovirus* from Tanzania. *Archives of Phytopathology and Plant Protection* 35 (4): 269–278.

Kashina, B. D., Mabagala, R. B. and Mpunami, A. A. (2002b). Molecular characterization of isolates of tomato yellow leaf curl virus from Tanzania. *Archives of Phytopathology* 35: 225–267.

Kaushik, S. K, Tomar, D. S. and Dixit, A. K. (2011). Genetics of fruit yield and it's contributing characters in tomato (*Solanum lycopersicom*). *Journal of Agricultural Biotechnology and Sustainable Development*3: 209-213.

Kennedy, J. S., Day, M. F. and Eastop, V. F. (1962). *AConspectus of Aphids as Vectors of Plant Viruses*. London Comm. Inst. Ent..

Khan, M. S., Tiwari, A. K., Khan, A. A., Ji, S. H. and Chun, S. C. (2013). Current Scenario of *Tomato yellow leaf curl virus*(TYLCV) and its Possible Management. *International Journal of Plant Research 26* (1): *139-147.*

Khan, I. A. (1997). Occurrence, distribution, host range, symptomatology and purification of ToMV on tomato. *PakistainJournal of Zoololgy* 29 (4): 385-389.

Knapp, S., and Darwin.S. C. (2006). Proposal to conserve the name *Solanum cheesmaniae* (L. Riley) Fosberg against *S. cheesemanii* Geras. (Solanaceae). *Taxonomy* 55: 806–807.

Knapp, S.(2002). Floral diversity and evolution in the Solanaceae. In *Developmental genetics and plant evolution*.. Q. C. B. Cronk, R. M. Bateman, and J. A. Hawkins, 267–297. London: Taylor & Francis.

Kolawole, O. M. Kayoed, R. M. O and Aina, J. (2010). The drying effect of varying light frequencies on the proximate and microbial composition of tomato. *Journalof Agricultural Science* 2 (2): 1916-9752.

Konaté, G., Barro, N., Fargette, D., Swanson M. M. and Harrison, B. D. (1995). Occur- rence of whitefly-transmitted geminiviruses in crops in Burkina Faso. *Annals of Applied Biology* 126: 121-129.

Kuti, J. O. and Molline H. E. (1984). A mild strain of tomato aspermy virus isolated from tomato in Maryland. *Plant Disease* 68: 959-961.

Lal, S. B. and Singh, S. (1988) Identification of some virus diseases of vegetable crops in Afghanistan. *Plant Protection Bulletin* 36 (2): 83-89.

LaMondia, J. A., Smith, V. L., and Douglas, S. M. (1999). Host range of *Oidium lycopersicum* on selected solanaceous species in Connecticut. *Plant Disease* 83:341-344.

Lana, A. F. and Adegbola, M. O. K. (1977). Important virus diseases in West African Crops.*Review of Plant Pathology* 56 (10): 849-868.

Lana, A. F. and Wilson, G. F. (1976). A new virus-like disease of tomato in Nigeria. *Plant Disease* 60: 296-98.

Lapidot, M., and Friedmann, M. (2002). Breeding for resistance to whitefly-transmitted geminiviruses. *Annals of Apply Biology* 140: 109-127.

Lapidot, M., Frieedmann, M., Pilowsky M., Ben-Joseph R. and Cohen, S. (2001). Effect of resistance to Tomato yellow leaf curl virus (TLCV) on virus acquisition and transmission by its whitefly vector. *Phytopathology* 90: 1209–1213.

Lenucci, M. S., Cadinu, D., Taurino, M., Piro, G. and Dalessandro, G. (2006). Antioxidant composition in cherry and high-pigment tomato cultivars. *Journal of Agricultural Food Chemistry* 54: 2606-2613.

Macintosh, S., Robinson, D. J., and Harrison, B. D. (1992). Detection of three whitefly transmitted geminiviruses occuring in Europe by tests with heterologous monoclonal antibodies. *Annals of Applied Biology* 121: 297-303.

Maiti, R. K., Amitava, Bakshi. and Sarkar, N. C. (2008). Abiotic factors affecting tomato productivity,mechanisms of adaptation and management strategy. *International Journal of Agriculture, Environment andBiotechnology* 1 (2): 9-35.

Marjan, K., James, H. B, and Anthony, P. K. (2000). Tomato Diseases and Disorders. Home and Garden Information Center. Clemson Cooperative Extension. Pp. 14

Mason, G., Rancati, M., and Bosco, D. (2000). The effect of thiamethoxam, a second generation neonicotinoid insecticide, in preventing transmission of *Tomato yellow leaf curl geminivir*us (TYLCV) by the whitefly *Bemisia tabaci* (Gennadius). *Crop Protection* 19: 473-479.

Matthews, R. E. F. (1991). *Plant Virololgy* pp 1-815.

Mayo, M. A. and Brunt, A. A. (2005). *Plant Virus Taxonomy: Families, Genera, and Type Species of plant viruses and viroids*, ICTV, 1 p.

Mazyad, H. M., Peters, D. and Maxwell, D. (1994). Tomato yellow leaf curl virus in Egypt: epidemiological and management aspects. 1st International Symposium on Geminiviruses, Almeria, Spain. Miron, D., & Schaffer, A. (1991). Sucrose phosphate synthase, sucrose synthase and acid invertase activities in developing tomato fruit of Lycopersicon esculentum Mill, and sucrose accumulating Lycopersicon hirsutum Humb and Bonpl. *Plant Physiology* 95: 623–627.

Megan, F. H., Rowena, J. G., Jane, R. M. and Graham, H. (1996). The incidence of chrysamthemum B. carlavirus, tomato aspermy cucumovirus, tomato spotted wilt tospovirusin Australian chrysanthemum crops Australia. *Plant Pathology* 25 (5): 174-178.

Momol, M. T., Simone, G. W., Dankers, W., Sprenkel, R. K., Olson, S. M., Momol, E. A., Polston, J. E. and Hiebert, E. (1999). First report of Tomato yellow leaf curl virus in tomato in South Georgia. *Plant Disease* 83: 487.

Moneruzzaman, K. M., Hossain, A. B. M. S., Sani, W., Saifuddin, M. and Alenazi, M. (2009). Effect of harvesting and storage conditions on the post harvest quality of tomato (*lycopersicon esculentum* mill) cv. roma VF. *Australian Journal of Crop Science* 3 (2): 113-121.

Morin, S., Ghanim, M., Zeidan, M., Czosnek, H., Verbeek, M., and van den Heuvel, J. F. J. M. (1999). A GroEL homologue from endosymbiotic bacteria of the whitefly *Bemisia tabaci* is implicated in the circulative transmission of Tomato yellow leaf curl virus. *Virology* 30:75-84.

Moriones, E., and Navas-Castillo, J. (2000). Tomato yellow leaf curl virus, an emerging virus complex causing epidemics worldwide. Virus Res. 71: 123 – 134.

Mourvaki, E., Gizzi, S., Rossi, R. and Rufini. S. (2005). Passionflower Fruit. A New Source of Lycopene. *Journal of Medicinal Food* 8 (1): 104-106.

Mutwiwa, U. N., Borgemeister, C., Von Elsner, B. and Tantau, H. J. (2005). Effects of UV absorbing plastic films on greenhouse whitefly (*Homoptera*: *Aleyrodidae*). *Journal of Economic Entomology* 98: 1221-1228.

Nagaraju, R. and Reddy, H. R. (1980). Occurrence and distribution of bell pepper viruses around Bangalore. Current research, University of Agricultural Sciences, Bangalore 10 (9/10): 155; 6.

Naika, S, Juede J, Goffau M, Hilmi M. and Dam, V. (2005). "Cultivation of Tomato" Production, processing and marketing, Agromisa/ CTA. Revised edition, *Agrodokserie*s No 17.

Nakhla, M. K., Maxwell, D. P., Martinex, R. T., Caryalho, M. G. and Gilbertson, R. L. (1994). Wide spread occurrence of the eastern mediteranean strain of tomato yellow leaf curl geminivirus in tomatoes in the Dominican Republic. *Plant Disease* 78: 926.

Nakhla, M. K., Mehta, P., Wyman, J. A., Stout, J. and Maxwell, D. P. (1994). Construction of infectious clones of *Tomato yellow leaf curl virus* from polymerase chain reaction – amplified fragments. *The American Society for Virology*, 13th Annual Meeting July 1994, Madison, WI.

Nakhla, M. K., El-Hammady, M. and Mazyad, H. M. (1978). Isolation and identification of some viruses naturally infecting tomato plants in Egypt. In 4th Conf. Pest Control, NRC,Cairo. pp. 1042- 051.

Narayana, Y. D., Bandyopadhyay, R, Navi, S. S. and Muniyappa, V.(2002). Sorghum viruses in Asia and Africa. ***In*** Leslie, J.F. (Ed.), *Sorghum and MilletDiseases: 2nd World Review* (pp.431-439). Ames, IOWA: IOWA State Press.

Nitzany, F. E. (1975). Tomato yellow leaf curl virus. *Phytopatholoy of Mediterranean* 14: 127 - 129.

Nono-Womdim, R. (2004). An overview of major virus diseases of vegetable crops in Africa and some aspects of their control. International Institute of Tropical Agriculture (IITA), Ibadan.

Nono-Womdim, R., Swai, I. S., Green, S. K., Gebre-Selassie, K., Laterrot, H., Marchoux, G. and Opena, R. T. (1996). Tomato viruses in Tanzania: Identification, distribution and disease incidence. *Journal of South African Society Horticultural Science* 6: 41 - 44.

Nono-Womdim, R. and Atibalentja, N. 1993. Identification and characterisation of *Pepper veinal mottle virus* in Cameroon. *Plant Protection Bulletin* 41: 121 - 123.

Norism E. Hedalgo, E. Accotto, G. P. and Moriones, E. (1994). High similarity among the tomato yellow leaf curl virus isolates from west Mediterranean Basin: the nucleotide sequence of an infectious clone from Spain. *Archives of Virology* 135: 165-170.

Norman, J. C. (1992). *Tropical vegetable crops*. IIfracombe Devon Publishers. 52-77.

Ohlendorf, B., Moratorio, B. M. and Yao, G. (2004). Yolo County Master Garden, University of California and USDA. Co-Operating.

Olaniyi, J. O., Akanbi, W. B., Adejumo, T. A and Akande, O. G. (2010). Growth, fruit yield and nutritional quality of tomato varieties. *African Journal of Food Science* 4 (6): 398 – 402.

Orzolek, M. D., Bogash, M. S., Harsh, M. R., Lynn, F., Kime, L. F., Jayson, K. and Harper, J. K. (2006). Tomato Production. Agricultural Alternatives Pub. Code # UA291. Pp. 2-3..

Osei, K., Osei, M. K., Mochiah, M. B., Lamptey, J. N. L., Bolfrey-Arku, G. and Berchie, J. N. (2012). Plant parasitic nematodes associated with tomato in Ghana. *Nematology of Mediterranean* 40: 33-37 33.

Osemwegi, O. O., Oghenekaro, A. O. and Owolo, L. O. (2010). Effect of pulverized *Ganoderma* spp., on *Sclerotium rolfsii Sacc* and Post-harvest tomato fruit preservation. *Journal of Applied Science and Research* 6: 1794-1800.

Padidam, M., Beachy, R. N. and Fauquet, C. M. (1995). Classification and identification of geminiviruses using sequence comparisons. *General Virology* 76: 249 – 263.

Palumbo, J. C., Horowitz, A. R. and Prabhaker, N. (2001). Insecticidal control and resistance management for *Bemisia tabaci*. *Crop Protection* 20: 739-765.

Palukaitis, P. and Garcı´a-Arenal, F. (2003). Cucumoviruses. *Advances in Virus Research* 62: 241–323.

Palukaitis, P., Roossinck, M. J., Diecgen, R. G. and Francki, R. I. B. (1992). Cucumber mosaic virus //*Advances in Virus Research* 41: 280–348.

Papayiannis, L. C., Katis, N. I., Idris, A. M. and Brown, J. K. (2011). Identification of weed hosts of *Tomato yellow leaf curl virus* in Cyprus. *Plant Disease* 95: 120 - 125.

Paran, I. and van der Knaap, E. (2007). Genetic and molecular regulation of fruit and plant domestication traits in tomato and pepper. *Journal of Experimental Botany* 58 (14): 3841-3852.

Pares, R. D., Gunn, L. V., and Cresswell, G. C. 1992. Tomato mosaic virus infection in a recirculating nutrient solution. *Journal of Phytopathology* 135 (3), 192 - 198.

Parvin, M. S., Akanda, A. M., and Rahman, A. H. (2007). Summer Cosmos – A Host of *Cucumber mosaic virus. Journal of Agriculture and Rural Development* 5 (1&2): 84-93.

Petro-Turza, M. (1987). Taste of tomato and tomato products. *Food Reviews International* 2 (3): 309–351.

Pfleger, F. L. and Zeyen, R. J. (2008). Tomato-Tobacco Mosaic Virus Disease. University of Minnesota Extension.www.extension.umn.edu/distribution horticulturedg1168.

Pico, B., Diez, M. J. and Nuez, .F (1996). Viral disease causing the greatest economic loss to the tomato crop-II. The tomato yel low leaf curl virus – *A review. Scientia Horticulturae* 67: 151–196

Pohar, K. S., Gong, M.C., Bahnson, R., Miller, E.C. and Clinton, S K. (2003). Tomatoes, lycopene and prostate cancer: a clinician's guide for counseling those at risk for prostate cancer. *World Journal of Urology* 21 (1): 9-14.

Polston, J. E. and Anderson, P. K. (1997). The emergence of whitefly transmitted geminiviruses in tomato in the western hemisphere. *Plant Disease* 81: 1358-1369.

Prasada Rao, R. D. V. J. and Yaraguntaiah, R. C. (1979). The occurrence of Pepper veinal mottle virus on chili in India. Mysore. *Journal of Agricultural Science* 13 (4): 445-448.

Pringle, C. R. (1999). Virus Taxonomy. The Universal system of virus taxonomy updated to include the new proposals ratified by the International Committee on Taxonomy of Viruses during 1998. *Archives of Virology* 144: 2.

Quinn, J. G. (1980). A Review of Tomato Cultivar Trial in the Northern States of Nigeria. In: *SamaruMiscellaneous Papers*. pp 84. Institute for Agricultural Research, Ahmadu Bello University, Zaria.

Ramalan, A. A. (1994). Irrigation and Environment: The state of Research and Development at the Institute for Agricultural Research, IAR, Samaru. *NOMA Magazine* 1994 (11): 16-19.

Reid, M. S. (2002). Maturation and Maturity Indices. University of California, Agriculture and Natural Resources Publication 3311, Oakland.

Roberts, I. M., Robinson, D. J. and Harrison, B. D. (1984). Serological relationships and genome homologies among Geminiviruses. *Journal of General Virology* 65: 1723 - 1730.

Roossinck, M. J., Zhang, L. and Hellwald, K. H. (1999). Rearrangements in the 5□ nontranslated region and phylogenetic analyses of *Cucumber mosaic virus* RNA3 indicate radial evolution of three subgroups. *Journal of General Virology* 73 (8): 6752–6758.

Rubinstein, G. and Czosnek, H. (1997). Long-term association of *Tomato yellow leaf curl virus (*TYLCV) with its whitefly vector *Bemisia tabaci*: effect on the insect transmission capacity, longevity and fecundity. *Journal of General Virology* 78: 2683- 2689.

Rukhsar, A. D., Sharmal J. P. and Mushtaq, A. (2015). Genetic diversity among some productive genotypes of tomato (*Lycopersicon esculentum* Mill.). *African Journal of Biotechnology*14 (22): 1846-1853.

Sanchez-Campos, S., Navas-Castillo, J., Monci, F., Dia,z J. A. and Moriones, E. (2000). *Mercurialis ambiqua and Solanum luteu*: Two newly discovered natural hosts of tomato yellow leaf curl Geminivirus.*Journal of Plant Pathology* 106: 391–394.

Sangoyomi, T. E., Owoseni, A. A., Adebayo, O. S. and Omilani, O. A. (2011). Evaluation of some botanicals against bacterial wilt of tomatoes. *International Research Journal of Microbiology*2: 365-369.

Sastry, K. S. and Zitter, T. A. (2014). Plant Virus and Viroid Diseases in the Tropics, doi: 10.1007/978-94-007-7820.

Sastry, K. S. (1982). Identification of pepper veinal mottle virus on tomato (*Lycopersicon esculentum* Mill) in India. *Current Science* 51 (5): 239-341.

Shankara, N., Joep van L. J., Marja G., Martin H., and Barbara D. (2005). Cultivation of tomato, production, processing and marketing.Printed by Digigrafi, Wageningen, Netherlands. pp92.

Shi, B. J., Li, Y. Y., Zhang, C. L. and Hua, R. M. (1993). Identi®cation of a viral isolate infecting chrysanthemum (for medicinal usage). *ActaPhytopathologica Sinica* 23: 231-236.

Sikora, E. J. (1998). Virus diseases of Tomato. Alabama Cooperative Extension System. Alabama A & M and Auburn Universities. 4pp.

Simons, J. N., Sobulo, R. A. (1975). Methods for higher tomato yield. *Bulletin Ministry of Agriculture and Natural Resources Western Nigeria*, 10-26pp.

Sokoto Agricultural Development Project (2008). Surveys and yields of tomato in Sokoto State (unpublished).

Srinivasan, R. (Ed.). (2010). Safer tomato production methods: Afield guide for soil fertility and pest management. AVRDC-The World Vegetable Centre, Shanhua, Taiwan. AVRDC Publication No. 10-740. 97p.

Ssekyewa, C. (2006). Incidence, Distribution and Characteristics of Major Tomato Leaf Curl and Mosaic Virus Diseases in Uganda. PhD-thesis. Faculty of Bioscience Engineering, Ghent University, Ghent, Belgium. 233 pp.

Tan, H., Thomas-Ahner, J. M., Grainger, E. M., Wan, L., Francis, D. M., Schwartz, S. J., Erdman Jr, J. W., Steven K.and Clinton, S. K. (2010). Tomato-based

food products for prostate cancer prevention: What have we learned? *Cancer Metastasis Reviews* 29:553–568.

Teasdale, J. R. and Abdul-Baki, A. A. (1995). Soil temperature and tomato growth associated with Black polythene and Hairy Vetch Mulches. *Journal of the American Society for Horticultural Science,* (120): 706-882..

Thomas, J. E., Massaloki, P. R. and Harrison, B. D. (1986). Production of monoclonal antibodies to *African cassava mosaic virus* and differences in their reactivities with other whitefly transmitted geminiviruses. *Journal of General Virology* 67: 2739 – 2748.

Thomson, A. D. (1962). Occurrence of tomato asperny virus, carnation mottle virus and a virus from chrysanthmus in New Zealand. *New Zealand Journal of Agricultural Research* 5: 396-402.

Thybo, A. K., Edelenbos, M., Christensen, L. P., Sørensen, J. N. and Thorup-Kristensen, K. (2006). Effect of organic growing systems on sensory quality and chemical composition of tomatoes. *LWT-Food Science and Technology* 39: 835–843.

Toivonen, P. M. A. (2007) Fruit maturation and ripening and their relationship to quality. *Stewart Postharvest Reviews* 3:1–5.

Valverde, R. A., Lotrakal P. and Landry, A. D. (2001). First report tomato leaf curl virus in Lousiana. *Plant Disease* 85: 230.

Verma, N., Mahnghara, B. K. Ram, R. and Zaidi, A. A. (2006). Coat protein sequence shows that *Cucumber mosaic virus* isolate from geraniums (*Pelargonium* spp.) belongs to subgroup II. *Journal of Biosciences* 31(1): 47–54.

Villareal, R. L. (1992). *Tomatoes in the tropics*. Colorado West view press. pp97, 103 -104.

Villareal, R. L. (1980). *Tomato in the Tropics Bulletin*. Colorado West Press Incorporated. 194 – 196.

Watkins, C. B. (2006). The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. *Biotechnology Advances* 24:389-409.

Willcox, J. K., Catignani, G. L. and Lazarus, S. (2003). Tomatoes and cardiovascular health. *Critical Reviews in Food Science and Nutrition*43:1–18.

Wisler, G. C., Duffus J. E., Lui H. Y. and Li, R. H. (1998). Ecology and Epidemiology of whitefly transmitted closteroviruses. *Plant Disease* 82: 270 - 280.

Wittwer, S. H. (1998). *The Encyclopedia Americana International edition* 26: 32 - 833.

Yang, Y., Sherwood, T. A., Patte, C. P., Hiebert, E.,and Polston, J E. (2004). Use of *Tomato yellow leaf curl virus* (TYLCV) rep gene sequences to engineer TYLCV resistance in tomato. *Phytopathology* 94: 490-496.

Yassin, A. M. (1975). Epidemics and chemical control of leaf curl virus disease of tomato in the Sudan. Experimental Agric 11: 161-165. http:// journals.cambridge.or g/action/displa yAbstract? fr omPage=o nline&aid=1603396.

Yassin, A. M. and Nour, M. A. (1965). Tomato leaf curl disease in the Sudan and their relation to tobacco leaf curl. *Annals of Appliedl Biology* 56: 207-217.

Zitter, T. A. (1984). Virus diseases and disorders of tomato.Vegetable crops. Fact sheet. pp735.

APPENDICES

Appendix I: Sample of structured questionnaire administered

structured questionnaire administered in Sokoto and Zamfara States in February, 2016 through an interpreter to elicit information from the farmers.

Objective: Occurrence and distribution of viruses associated with tomato in Sokoto and Zamfara States respectively**.**

Section A: Background information of the respondent (farmer).

STATE: …….

LGA: …….

VILLAGE: ……

Gender of Farmer: Male ( ) Female ( )

Age of Farmer ……...

Highest Educational Certificate. (A) Non-formal (B) Primary (C) Post-primary

Section B: Production practices of famer.

1.What is the size of your tomato farm?.....

2. For what purpose do you grow tomato (A) consumption (B) market(C) both

3. State approximately how long you have you been cultivating tomato …….

4. Which type of land preparation do you employ for cultivation of tomato?

(A) Flats (B) ridges (C) Raised basins (D) Sunken basins

5. Do you treat your tomato seeds before planting? (Yes)(No)

6. If yes, what type of treatment do you use before planting your seeds?

(A) Pesticide (B) sun-heating (C) ash (D) salt soak (E) others (specify)

7. Do you grow tomato on the field as (A) sole crop (B) mixed crop

If yes as mixed crop, name the other crops ……...

8. If as sole crop, do you practice crop rotation (A) Yes (B) No?

9. If yes, what other crops do you rotate tomato with? ……..…....

10. What length of crop rotation do you practice? (A) 2-3 (B) 3-5 (C) above5 years

11. What type of fertilizers do you apply on tomato? (A) Inorganic (B) organic (C) both

12. What type of crops are planted surrounding your farm?.....

13. What type of crop protection practices do you employ in your farm?.....

14. What type of sanitary measures do you practice?……

15. What is approximate age of your crop? (A) ≤ 4 weeks (B) 5-9 weeks (C) ≥ 9weeks

16. Where do you get your seeds? (A) Market (B) Seed company (C) From previous season

17. What type of variety do you plant? (A) Improved (B) local (C) both

Appendix II: Compositions of buffers used

Coating buffer (pH 9.6)

1.59 g sodium carbonate (Na_2CO_3), 2.93 g sodium bicarbonate ($NaHCO_3$), 0.20 g sodium azide (NaN_3) will be dissolved in 900 ml H_2O, adjust pH to 9.6 with HCl and make up to 1 l.

PBS (pH 7.4) phosphate buffered saline

8.0 g sodium chloride (NaCl), 0.2 g potassium chloride (KCl), 0.2 g monobasic potassium phosphate (KH_2PO_4), 1.15 g dibasic sodium phosphate (Na_2HPO_4), 0.2 g sodium azide (NaN_3) will be dissolved in 900 ml H_2O, adjust pH to 7.4 with NaOH or HCl and make up to 1 l.

PBS-Tween (PBST)

PBS + 0.5 ml Tween 20 per liter.

Sample extraction buffer (pH 8.5)

0.05 M Tris containing 0.06 M sodium sulfite, pH 8.5.

Conjugate buffer

PBST + 2 % PVP + 0.2 % egg albumin.

Substrate buffer

97 ml diethanolamine, 600 ml H_2O, 0.2 g sodium azide (NaN_3), pH will be adjusted to 9.8 with HCl and make up to 1 liter with H_2O.

Appendix III: Geographic and Disease Data in Sokoto State, 2016 dry season.

LGA	Location	Co-ordinate	Elevation (m)	Area (m^2)	No of plants observed	No of symptomatic plants	Virus disease incidence (%)	Symptoms observed
Raba	Majiyan Tambari	N13^{0}07.145' E005^{0}29.151'	247	1000,1	265	118	46.0	Cl, M, N, D
	Maikujera	N13^{0}07.204' E005^{0}29.274'	255	1422.4	157	53	33.8	Cl, M, St, C
	Tofa	N13^{0}07.203' E005^{0}29.273'	254	2026.7	213	108	50.1	
Kware	Kiyasa	N13^{0}06.434' E005^{0}16.050'	245	459.6	340	211	62.0	Cl, M, St, C
	Anguwar lalle	N13^{0}07.159' E005^{0}15.114'	242	1144.3	289	165	57.0	Cl, M, N
	Gidan kwano	N13^{0}06.307' E005^{0}15.899'	245	3666.0	188	96	51.0	M,Mt, St, C
Tureta	Marna	N12^{0}35.813' E005^{0}32.322'	266	10,565	211	160	75.8	M,Mt, D,N
	Tsamiya	N12^{0}35.838' E005^{0}32.286'	251	3522.2	217	63	29.0	Cl, M, St, C
	Magina	N12^{0}35.469' E005^{0}32.486'	265	368.2	157	98	62.0	Cl, M, C, N, D

Cl= Leaf curl, M= Mosaic, Mt= Mottling, D=Distortion, St= Stunting, C= Chlorosis, N= Necrosis.

Appendix IV: Agronomic Data at Tomato Farms in Sokoto State, 2016 dry season

LGA	Location	Cropping history (year)	Co-ordinate	Cropping pattern	Elevation (m)	Surrounding crops	Area (m^2)	Protection practices	No of plants observed	Field hygiene	No of symptomatic plants	Age of crop (WAT)	Virus disease incidence (%)	Source of seed	Symptoms observed	Variety planted
Raba	Majiyan Tambari	6		Sole cropping		Onion, garlic		Chemicals		weedy		3		Seed company		Dan Eka
	Maikujera	5		Mixed cropping		Onion		Chemicals		weedy		7		Market		UTC
	Tofa	10		Mixed cropping		Tomato, onion		Chemicals		weedy		6		Previous season		UTC
Kware	Kiyasa	6		Mixed cropping		Onion, maize, rice, maize		Chemicals		weedy		5		Previous season		Dan Eka
	Anguwar lalle	15		Sole cropping		Onion, sweet potato		Chemicals		weedy		7		Previous season		Dan Eka
	Gidan kwano	40		Sole cropping		Onion.		Chemicals		weeded		4		Previous season		UTC, Dan Eka
Tureta	Marna	8		Mixed cropping		Tomato, okro. pepper		Chemicals		weedy		7		Previous season		Dan Eka
	Tsamiya	17		Mixwd cropping		Tomato, onion, lettuce, okro		Chemicals		weedy		3		Market		Dan Eka
	Magina	7		Mixed cropping		Tomato, maize, cabbage,		Chemicals		weeded		8		Market		Dan Eka, Dan Zaria.

Tsafe	Yankuzo	N11^{0}55.561' E007^{0}03.243'	512	543.0	98	69	71.0	Cl, M, N
	Dan amanawar Galadima	N11^{0}55.464' E007^{0}03.219'	506	413.5	556	345	62.0	CL, N, C
	Takulwa	N11^{0}55.457' E007^{0}03.237'	513	398.0	624	430	68,9	CL, M, C D
Talata Mafara	Tungar Kwate	N12^{0}35.472' E006^{0}06.674'	303	663.0	348	221	63.5	Cl, M, D, N
	Umra	N12^{0}35.535' E006^{0}06.047'	312	2332.0	415	260	62.0	Cl, M, Mt,
	Hura	N12^{0}35.492' E006^{0}06.621'	307	1008.0	329	233	70.8	Cl, M, C, St
Bakura	Kwanar Kalgo	N12^{0}34.625' E005^{0}59.197'	299	3328,0	327	254	77,7	M, C, St
	Yargeda 1	N12^{0}34.603' E005^{0}359.205'	301	4692.0	312	147	47.01	Cl, D, N
	Yargeda 11	N12^{0}34.642' E005^{0}39.156'	295	3488.0	199	84	42.2	M, D, C, N

Appendix V: Geographic and Disease Data in Zamfara State, 2016 dry season.

Cl= Leaf curl, M= Mosaic, Mt= Mottling, D=Distortion, St= Stunting, C= Chlorosis, N= Necrosis.

Appendix VI: Agronomic Data at Tomato Farms in Zamfara State, 2016 dry season

LGA	Location	Cropping history (year)	Cropping pattern	Surrounding crops	Protection practices	Field hygiene	Age of crop (WAT)	Source of seed	Variety planted
Tsafe	Yankuzo	20	Sole cropping	Tomato, onion	Chemicals	weedy	9	Previous season	UTC
	Dan amanawar Galadima	18	Sole cropping	Tomato, onion	Chemicals	weedy	7	Seed company	UTC
	Takulwa	12	Sole cropping	Tomato, onion	Chemicals	weeded	9	Seed company	UTC
Talata Mafara	Tungar Kwate	10	Mixed cropping	Onion, sweet potato	Chemicals	weedy	5	Previous season	UTC, Dan Gombe, Dan Eka
	Umra	15	Mixed cropping	Onion, sweet potato	Chemicals	weeded	7	Previous season	UTC, Dan Gombe
	Hura	20	Mixed cropping	Onion, amaranthus	Chemicals	weeded	8	Previous season	UTC, Dan Eka
Bakura	Kwanar Kalgo	8	Sole cropping	Tomato	Chemicals	weedy	7	Previous season	UTC, Dan Eka
	Yargeda 1	17	Sole cropping	Tomato, onion	Chemicals	weedy	3	Market	Dan Eka
	Yargeda 11	6	Mixed cropping	Tomato	Chemicals	weeded	7	Previous season	Dan Eka, Dan Dino