SURVEY OF ETHIOPIAN PEPPER MOTTLE VIRUSES IN THE CENTRAL RIFT VALLEY OF ETHIOPIA AND EVALUATION OF NETTING DURATION AS MANAGEMENT OPTION

MSc Thesis

KUMSA DIDA FAYE

HAWASSA UNIVERSITY

College of Agriculture

Hawassa, Ethiopia

October, 2018

SURVEY OF ETHIOPIAN PEPPER MOTTLE VIRUSES IN THE CENTRAL RIFT VALLEY OF ETHIOPIA AND EVALUATION OF NETTING DURATION AS MANAGEMENT OPTION

KUMSA DIDA FAYE

MAJOR ADVISOR: ALEMAYEHU CHALA (PhD)

CO-ADVISOR: FERDU AZEREFEGNE (PhD)

A Research Submitted to the School of Plant and Horticultural Science

HAWASSA UNIVERSITY

College of Agriculture

In Partial Fulfillment of the Requirements for the Degree of the Masters of Science in Agriculture (Specialization: Crop Protection)

Hawassa, Ethiopia

October, 2018

APPROVAL SHEET

SCOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

This is to certify that the thesis entitled **“Survey of Ethiopian Pepper Mottle Viruses in central the Rift Valley of Ethiopia and Evaluation of Netting Duration as Management Option”** submitted in partial fulfillment of the requirements for the degree of **Master’s** with specialization in **Crop Protection**, the graduate program of the **School of Plant and Horticultural Science, Hawassa University College of Agriculture** and has been carried out by **Kumsa Dida** under my /our supervision. Therefore I/we recommend that the student has fulfilled the requirements and hence here by can submit the thesis to the school.

Alemayehu Chala (PhD)	______________	____________
Name of major advisor	Signature	Date
Ferdu Azerefegne (PhD)	_____________	____________
Name of co-advisor	Signature	Date

DEDICATION

This thesis is dedicated to my family and my beloved late father who nursed me with affection and care, but he was not able to see the fruit of my work.

STATEMENT OF THE AUTHOR

First of all, I declare that this thesis is a result of my real work and that I have duly acknowledge all sources of materials referred to for writing it. I have submitted this thesis to Hawassa University in partial fulfillment of the Degree of Master of Science. The thesis is deposited at the library of the University to be made available to interested readers for reference. I honestly declared that I have not submitted this to any other institution so far for the award of any academic degree, diploma, or certificate.

Brief quotations from this thesis are allowed without requiring special permission provided that an accurate acknowledgement of the source is made but wishes for extended quotations from or reproduction of this manuscript in whole or part may be granted by the Head of the Department of Plant and Horticultural Sciences or by the Dean of the School of Graduate Studies of the University when in his or her judgment, the proposed use of the material is for a scholarly interest. In all other instances, permission must be obtained from the author.

Name: Kumsa Dida   Signature: ________________

Date of submission: __________________

ACKNOWLEDGEMENT

Above of all, I thank Almighty God for giving me the help, strength and good health in achieving all my academic endeavors.

I am particularly grateful to my instructors and advisors Dr. Alemayehu Chala and Dr. Ferdu Azerefegne for their helpful professional comments, guidance and overall support starting from research proposal up to thesis write up. You are the one who made this work feasible. I have no words to express my respect and to say thank you for all your support and extraordinary comments. Also I would like to thank IPM Vegetable project for financial support for this thesis work.

My appreciation also goes to my special friends Hundesa Fufa, Biruk Tesfaye, Hachalu Kinfu, Adisu Mosisa, and Adem Abe for their motivation idea, facilitating my study, advising and commenting my work.

Finally, I thanks to all my family members who contributed towards my success and indispensable friends who gladly shared my responsibilities.

TABLE OF CONTENTS

Contents **pages**

LIST OF ABREVIATIONS

ANOVA	Analysis of variance
CMV	Cucumber Mosaic Virus
CSA	Central Statistical Agency
DAT	Days After Transplanting
EEPA	Ethiopian Export Promotion Agency
EPMV	Ethiopian Pepper Mottle Virus
GLM	General Linear Model
MARC	Melkasa Agricultural Research Center
PVY	Potato Virus Y
RCBD	Randomized Complete Block Design
SAS	Stastical Analysis System
TEV	Tobacco Etch Virus
TSWV	Tomato Spotted Wilted Virus
YWT	Yellow Water Trap

LIST OF TABLES

Table **pages**

LIST OF FIGURES

Figures **pages**

LIST OF TABLES IN APPENDIX

Appendix Tables **Pages**

Survey of Ethiopian Pepper Mottle Viruses in the Central Rift Valley of Ethiopia and Evaluation of Netting Duration as Management Option

By

Kumsa Dida

Major advisor: Alemayehu Chala (PhD)

Co-advisor: Ferdu Azerefegne (PhD)

ABSTRACT

Ethiopian pepper mottle virus is one of the major constraints of pepper production in the central rift valley region of Ethiopia. The present study was conducted to assess the prevalence of Ethiopian pepper mottle virus in the region and to determine optimum netting duration for efficient protection of pepper from vector infestation and subsequent viral infection. For this purpose, field survey and an experiment was carried out in the central rift valley of Ethiopia. The survey was conducted on 60 pepper fields in three districts i.e. Butajira, Meki and Ziway districts. Data were collected on the incidence of viral disease, plant height and number of pods per plant. In addition, field experiments were carried out at Hawassa and Meki to assess the efficacy of netting duration against aphid vectors and viral diseases. Data were collected on the number of aphid populations, virus incidence, and pepper growth parameters and yield. Visual inspection of the surveyed fields revealed that almost all the pepper fields (99.6%) had viral diseases. Viral disease incidence ranged from 52.8% in Ziway district to 68.6% in Butajira district. Furthermore, significant variations at ($p<0.01$) were observed between treatments of the field experiments in terms of aphid infestation, virus incidence and pepper yield. Covering of plots with net for up to 60 or more days after transplanting reduced aphids' population per plant by a greater margin (61.8%-76.9% in Hawassa; 52.4-67% in Meki) and virus incidence by 48%-60.8% in Hawassa and 38.6%-48.5% in Meki as compared to the control plots. Total and marketable yields were significantly higher in plots protected by net for up to 60 days or more after transplanting while unmarketable yields were low in those plots. Low virus incidence and aphids' population in plots covered by net up to 60 days after transplanting and longer resulted in increased yields by 44 %-55 % in Hawassa and 38 %-49.5 % in Meki as compared to the control plots. Unmarketable yield was positively correlated ($p<0.001$) with aphids population and virus incidence while total and marketable yields were negatively correlated with aphids population and virus incidence. The current results suggest the need to apply control measures at early growth stages to effectively protect pepper plants from aphids and associated viruses.

Key words: aphid, Ethiopia, netting duration, pepper, viruses.

1. INTRODUCTION

Hot pepper (*Capsicums* spp.) is one of the main crops belonging to the family Solanaceae and used as fresh, dried or processed products, as vegetables and spices or condiments grown in different parts of the world (Acquaah, 2004). The genus *Capsicum* is the second main vegetable crop of the family after tomato Solanaceae in the world (Rubatzky and Yamaguchi, 1997; Berhanu *et al.,* 2011). Pepper is originated from Latin-America and grown all over the world for food and medicine (Mazourek *et al*., 2009). Pepper fruits vary in shape, color, pungency and texture. Fruits are commonly green before maturity but after maturity the color can be red, orange and yellow or purple (Russo and Biles, 2004).

Different types of vegetable crops are grown in Ethiopia under rain-fed and/or irrigation systems (Alemayehu *et al*., 2010). In many areas, pepper is grown as mono-crop and rotated with cereals or legumes, using the main rainy season. However, the production in dry season using irrigation can be found, particularly in the central rift valley parts of the country due to availability of irrigation facility (Alemayehu *et al*., 2010). Ecological isolations in pepper growing areas are common and there exists high variability in growing conditions and cropping systems. The crop is mostly grown in medium altitude (1400-2200 m above sea level) on sandy loam or clay loam soils with enough moisture holding capacity (Yosef and Yayehu, 1989; EHDA, 2011 and 2012).

Hot pepper serves as one of the important sources of food and income to smallholder farmers and as exchange earning commodity (Beyene and David, 2007). It is important part in the daily diet of most Ethiopian societies. The standard daily utilization of hot pepper by Ethiopian adult is estimated at 15 g, which is higher than most other vegetables (MARC, 2004). Hot pepper is a common vegetable and plays an important role in the national economy of the country. It serves as row material for the processing industries, essential cash crop to farmers and a supply of employment to urban and rural populations. Hot pepper production for dry pod has been low with a general average yields of 0.4 t/ha (Fekadu and Dandena, 2006). Pepper yields varies significantly from one region to other region due to several factors such as topography, lack of improved varieties, soil type, water quality, drought, insect pest, diseases, different cultural practices, soil tillage and fertilizer application (Liu *et al*., 2008; Delelegn, 2009).

Arthropod pests and diseases caused by different fungi, bacteria and viruses are the most important ones (Green and Kim, 1991). Viral diseases such as EPMV, potyvirus and fungal diseases like powdery mildew, stem and leaf blight, pod bleaching and damping off, and bacterial leaf spot have emerged as severe threats to the crop in the foremost producing areas (Yaynu *et al*., 1999; Tameru, 2004). Viruses are reported to cause total crop failure in addition to lowering yields and reducing fruit quality (Green and Kim, 1991).

More than 90 % viral disease incidences and absolute crop failure have been reported from various places in Ethiopia (Agranovsky, 1993; Tameru *et al*., 2003). Relative importance of viruses on pepper is quite erratic across regions, where a few viruses are common to a particular region. Ethiopian pepper mottle virus (EPMV), a potyvirus occurring in diverse or single infection, is the most significant virus in the rift valley and southern parts of Ethiopia (Agranovsky, 1993; Yaynu *et al*., 1999; Tameru *et al*., 2003). Local and regularly grown varieties such as ‘Markofana’ are highly susceptible to EPMV and aphids which help as vector to spread this disease (Tameru, 2004; Simon *et al*., 2009).

Crops and weeds in and around fields may affect the species diversity of vectors and are often potential sources of virus inoculum (Tameru *et al*., 2003). Simon *et al*. (2009) found several cultivated crops and volunteer plants that influenced the species composition of aphids present on pepper farms. The migratory habits of aphids make them important vectors of plant viruses. Peak aphid flights and the presence of known vectors are often associated with rapid spread of viruses in a particular area. In some case virus incidences are correlated with high numbers of inefficient vectors when the numbers of efficient vectors were low (DiFonzo *et al*, 1997; Simon *et al*., 2009).

Viral diseases can cause enormous losses in different crops terms of quantity and quality of products (Sastry, 2014). Virus diseases are not open to control by direct methods. Unlike fungicides and bactericides, no commercial viricides are developed. But a number of indirect control measures for different plant-virus suitable to varied agro ecosystems are developed which help to avoid the pathogen or minimize their impact on crop yields (Thresh, 2006). Virus diseases normally cause systemic infections and contain very effective methods of transmission. Some viral diseases like Ethiopian pepper mottle virus, tobacco etch virus (TEV), potato virus Y (PVY), cucumber mosaic virus (CMV), and tomato mosaic virus (TMV) are highly contagious and affect large number of hosts belonging to Solanaceae families (Tameru *et al*., 2003).

The epidemiology of viruses differ along with localities, time and a factor of local source of inoculum, vector complex involved and how the pretenses of vectors are harmonized with the phenology of the crop (DiFonzo *et al*., 1997). So understanding the epidemiology of aphid-borne viruses is very essential for the development of appropriate management strategies. The uses of cereal crops like wheat, maize, sorghum and pearl millet as barrier crops when the main crop is dicot family against non-persistent aphid-borne viruses in different crops like chilli, pepper, potato, beans, and soybean are effective in reducing the virus incidence under field conditions (Sastry, 2014).

Barrier crops, mulches and nets are used to decrease virus infection and vector infestation in several non-persistently transmitted plant viruses. For example, netting of okra plants for up to 4-5 weeks reduced the number of jassids and whiteflies as well as virus infection when compared with that of un-netted plants (Fajinmi and Fajinmi, 2010).

Although spreading of non-persistent viruses by aphids has inadequate specificity with respect to individual aphid species, some aphid species are more efficient in transmitting certain virus species than other aphid species (Eastop, 1977). Sometimes a less efficient vector can be more important in spreading a virus than more efficient vectors if it occurs in larger quantity (Raccah, 1983).

1.1. Statement of the Problem

Studies on viruses in Ethiopia are concentrated on their identification and characterization. Moreover, investigations on aphid vectors are also on the identification of species, flight behavior and population dynamics (Simon *et al*., 2009; Marame *et al*., 2010). On the other hand, studies on the management of the viruses and their aphid vectors are inadequate under Ethiopian conditions. In many virus-host plant patho-systems, plants are known to be very susceptible at the early growth stages (Muller, 1959; Tameru *et al*., 2003).

Previous investigations have reported a non-persistent efficient transmission of viruses by vectors (Yaynu *et al*., 1999; Tameru, 2004). There are some observations that showed early infection of pepper with viruses resulting in severe yield losses. Furthermore, aphids entering pepper fields at early stage cause severe epidemics of potyvirus such as Ethiopian pepper mottle virus, potato virus Y and tomato mosaic virus. However, identifying the most susceptible stage/s of pepper to vector infestation and virus infection helps to protect the crop at particular stage and to reduce infection level of virus and yield losses. This contributes further to the development of effective disease management strategies for pepper viruses and their aphid vectors.

1.2. Objectives

- To determine the prevalence of Ethiopian pepper mottle virus (EPMV) and aphids in the central rift valley of Ethiopia
- To determine optimum netting duration for efficient protection of hot pepper from aphids infestation and EPMV infection.
- To determine the effect of EPMV on fruit yield of hot pepper under different netting durations.

1.3 Hypothesis

Null hypothesis (H0): Netting duration does not affect aphid population, viral disease incidence and pepper fruit yield.

Alternative hypothesis (H1): Netting duration affects aphid population, viral disease incidence and pepper fruit yield.

2. LITERATURE REVIEW

2.1. Origin and Distribution of Pepper

Capsicums species are originated from around Mexico in the North and Bolivia in the south of Latin America (Purseglove *et al*., 1981). Spanish and Portuguese explorers distribute pepper across the world, i.e. first into Europe and then to Asia and Africa. Pepper is produced in all continents except Antarctica. Tropical Asia (India, Malaysia, Thailand, and Indonesia), and tropical Africa (North Africa, Senegal, Nigeria, Ghana and Kenya) and South America (Mexico) and Caribbean countries are the major producers (Dennis, 2013).

2.2. Production of Pepper in Ethiopia

Hot pepper is very important vegetable and spice crop grown in most part of Ethiopia under rain fall as well as under irrigation (Esayas, 2009). All domestic consumptions in the country come from production by subsistence farmers. Pepper has a unique traditional place, as dried powder from its pods is condiment of the daily diet of Ethiopian food. In addition, small scale farmers use pepper to generate income for various on and off-farm economic activities (Beyene and David, 2007). It is produced all over Ethiopia with the central (eastern and southern shewa), western, northwestern (Wollega and Gojjam), and the south part of the country are the potential pepper production but districts in central rifty valley are the major production area (Rahman *et al*., 2006).

CSA (2016/2017) report indicated that the estimated productions of peppers in Ethiopia were 627, 943.29 quintals from 9,832.28 ha in green form and 3,298,042.90 quintals of dry pepper from an area of 180,701.46 ha. According to the same report, the area covered by vegetables take up about 1.69 % of the area in all crops at national level and of all the area under vegetables, 75.41 % is under red peppers production. The standard productivity of the crop is 18.25 quintals per ha.

2.3. Importance of Pepper

Hot pepper (*Capsicum annuum* L.) is a vegetable crop at its green stage. Peppers are among the most heavily consumed spices all over the world. They are the most popular salad vegetables (Esayas, 2009). Dried ripe pods of many different varieties of *Capsicum* are utilized to prepare cayenne pepper, ground pepper and crushed red pepper (EEPA, 2003). This is because it increases the receipted of the insipid basic nutrient foods. Both sweet and hot peppers are processed into many types of sauces, pickles, relishes and canned products. According to Bosland and Votava (2000) hot peppers, contains vitamins A and C and good sources of B2, potassium, phosphorus and calcium.

Hot pepper is a significant vegetable crop both economically and nutritionally because it is a good source of natural color and antioxidant compounds (Ou *et al*., 2002). A wide spectrum of antioxidant vitamins, carotenoids, ascorbic acids, capsaicinoids and phenolic compounds are present in hot pepper fruits.

According to Bosland and Votava (2000), pepper is the mainly recommended tropical medication for arthritis. The pharmaceutical industry uses capsaicin as a counter-irritant cream, for external application of sore muscle (Thakur, 1993). Creams containing capsaicin have reduced pain associated with post operative pain for mastectomy patients and for amputees suffering from phantom limb pain. Expanded use of the cream has also been found to help reduce the itching of dialysis patients, the pain from shingles and cluster headache. Peppers also motivate the flow of saliva and gastric juices that serve digestion (Alicon, 1984).

2.4. Constraints of Pepper Production

The limited quantity and quality of pepper production in the world is largely attributed to biotic and a biotic stresses (Douglas, 2008; Tusiime *et al*., 2010). Abiotic factors affecting pepper productions include various environmental factors such as temperature, soil, humidity, light intensity and moisture (Rao *et al*., 2004). Temperature along with humidity is playing an important role in pepper production. Dorland (1974) stated that the maximum set of bell or sweet pepper occurs at temperatures of 18°C to 24°C, but temperatures below 16°C and high temperature above 32°C prevent fruit set. Temperature can also affect fruit quality; best fruit color is realized at temperatures from 18°C to 24°C. Night temperatures above 22°C lead to poor fruit set. Low humidity and high temperatures will cause abscission of buds, flowers and small fruits. Irregular rainfall distribution during fruit development exposes pepper to blossom end rot disorder. During the same period water stress lead to fruit and flower abortion.

Biotic factors like fungal, bacterial, viral diseases, nematodes, mites and many insect pests can cause significant losses in pepper production (Black *et al.*, 1991; Ochoa-Alejo and Ramirez-Malagon, 2001). The major limiting diseases of hot peppers are phyto pathogenic fungi, bacteria, and viruses. For example, 60 to 100 % losses of marketable fruit have been reported from virus infection (Green and Kim, 1991; Tameru *et al*., 2003). Bacterial spot caused by a seed borne bacterial pathogen (*Xanthomonas campestris* pv. *vesicatoria*) is also capable of causing severe defoliation of plants, resulting in reduced yield and loss of harvested fruit quality when severe damage occurs on enlarging fruits (Sun *et al*., 2002).

Peppers are also affected by different virus diseases such as pepper mottle virus, potato virus Y, tomato mosaic virus, tobacco mosaic virus, tobacco etch virus, and other virus like tomato spotted wilt virus, and cucumber mosaic virus (Agranovsky, 1993; Tameru *et al*., 2003). These virus diseases are important factors contributing to low yields and reduced fruit quality of pepper (Yaynu *et al*., 2001). Virus diseases cause serious losses in the pepper and the most limiting factor affecting pepper production (Makkouk and Gumpf, 1974). Sometimes total crop failure due to viral diseases had occurred and farmers were forced to lose their production due to high infection of viruses in the field (Tameru *et al*., 2003). Potyvirus such as Ethiopian pepper mottle virus, potato virus Y, Tomato mosaic virus and tobacco mosaic virus are very important viral diseases in pepper field in the rift valley parts of Ethiopia (Tameru, 2004).

In additions, pepper crops can be affected by different pests like aphids, thrips, whiteflies and worms such as bollworms and cutworms that cause damage to agricultural production by feeding on crops and transmitting viral disease. For example several species of aphids can be found on pepper plants and some of them can cause significant problem. Green peach aphids (*Myzus persicae*), cotton melon aphid (*Aphis gossypii*), and *Rhopalosiphum maidis* (corn leaf aphid), *Macrosiphum euphorbiae* (potato aphid) can cause the most problem on peppers (Simon *et al*., 2009). However, aphids are a vector of several important viruses on pepper, including cucumber mosaic virus, potato virus Y, tobacco etch virus, and pepper mottle virus (Tameru, 2004). Some vectors also produce sticky honeydew that is difficult to remove from fruit. Honeydew produced by vectors allows the development of sooty mold fungi, covering leaves and fruit with dark mold growth that reduce photosynthesis and lower fruit quality.

2.5. Viral Disease of Pepper

Viral disease belongs to genus potyvirus and the family potyviridae are occurred at rates up to 100 % in pepper fields (Martin *et al*., 1998). Pepper productions are strictly affected by virus diseases caused by aphid transmitted viruses, particularly pepper mottle virus (PMV), potato virus (PVY), tomato mosaic virus (TMV) and tobacco etch virus (TEV) (Tameru *et al*., 2003).

Potato virus Y (PVY) is the most common potyvirus infecting pepper. It occurs worldwide although it appears to be more important in warmer areas **(**Mills and Abdul, 1987). Mosaic, mottle, dark green, vein banding, vein clearing and yellowing are typical symptoms of infection by PVY, other symptoms such as leaf crinkling, leaf distortion and stunted growth are also common, depending on the virulence of the strain and the host pathogen interaction (Sharma *et al*., 1989). PVY is easily transmitted by sap inoculation (Thakur *et al*., 1988). PVY has flexuous thread-like (filamentous) particles ranging from 700-800 nm in length (Thakur *et al*., 1988).

Pepper mottle virus is one of the potyvirus genus, which causes mosaic disease of pepper cultivars (Nelson and Wheeler 1978). The most common symptom of pepper mottle is mottling of leaves, but other symptoms such as green vein banding, vein clearing, leaf deformation, stunting or dwarfing and necrosis can also occur on Solanaceous species such as *Capsicum annuum L., Lycopersicon esculentum, Nicotiana hybrid, N. tabacum, Physalis floridana* and other Solanum species (Purcifull *et al*., 1975). Pepper mottle virus is transmitted by aphids species such as green peach aphid (*Myzus persicae*), cotton melon aphid (*Aphis gossypii*), and cowpea aphid (*Aphis craccivora*) from infected host plants to health (Zitter, 1975). However, this virus is able to persist because vectors can carry the virus from infected peppers to native, perennial, solanaceous weeds such as *Datura stramonium* (jimson weed) and *Solanum elaeagnifolium* (silver leaf nightshade). Flexuous rod-shaped particles are found in crude extracts from pepper leaves infected with pepper mottle virus measuring between 729-745nm in length (Purcifull *et al*., 1975).

Pepper veinal mottle virus (PVMV) is another member of potyvirus genus which infects pepper plants (Atiri and Dele, 1985). Leaves of PVMV infected plants commonly develop chlorosis of the veins followed by systemic interveinal chlorosis. Mottle, vein chlorosis and small distorted leaves also occur. Leaf abscission and fruit distortions have also been reported (Brunt and Kenten, 1971). Alegbejo (1986) found that PVMV was transmitted by seven species of Aphids (*Myzus persicae*; *Hystero neurasetariae*, *Aphis gossypii*, *A. fabae, A. cracivora* and *Rhopalosiphum maidis*). Pepper veinal mottle virus had filamentous particles 700–750 nm in length (Agranovsky, 1993).

Tobacco etch virus (TEV) is a potyvirus; mainly important virus affecting pepper plants which has a filamentous particle which is 730x12nm in length (Myers, 1996). The virus causes chlorotic mottle and necrosis of pepper (Purcifull and Hiebert, 1982). Vein banding along the whole length of the veins is another typical symptom (Zitter *et al*. 1984). Agrios (2005) also reported that TEV infected pepper leaves showed mottling, mosaic and distortion; pepper fruit were distorted, and the entire plant may be stunted. Tobacco etch virus (TEV) was easily transmitted mechanically (Zitter, 1984). TEV is also transmitted in a non-persistent mode by aphids to over 150 plant species from more than 20 families (Edwardson, 1997). Twelve species of aphids have been identified as vectors of TEV (Eckel and Lampert, 1993). *Aphis gossypii Glover*, *Rhopalosiphum maidis, Lipaphis erysimi, Macrosiphum euphorbiae,* *Hyperomyzus lactucae and Myzus persicae* have been found in the pepper agro ecosystems in Ethiopia (Simon *et al*., 2009).

Tomato spotted wilt virus (TSWV) is known a member of genus tospovirus that infects pepper. It is known to cause chlorosis and yellow rings on pepper leaves and fruits. TSWV is transmitted persistently by thrips. This virus has a wide host range and it is very potentially damaging Solanaceae family (Jones *et al*., 1993).

Pepper crop is also strongly affected by other viruses like cucumber mosaic virus (CMV) from cucumovirus genus and alfalfa mosaic virus (AMV) from alfamovirus genus. These viruses are estimated to cause up to 50% loses in potential production of pepper varieties (Francki *et al*., 1979; Moyer, 1999).

2.6. Transmission of Vector Borne Viruses

Viral diseases are transmitted from infected plants to the uninfected plants through mechanical injuries on plant tissues by contaminated tools and insect vectors. Most of the pepper viruses are categorized under potyvirus genus. These viruses are transmitted in a non-persistent mode and epidemic levels of field spread often occur (Shukla *et al*., 1994). In addition, members of potyvirus genus are also sap transmissible and some of them are spread by seeds (Brunt *et al*., 1996). The rate and pattern increase of potyvirus within a pepper field is determined by the presence and behavior of its vectors, and the availability of a suitable source of virus inoculum (Irwin and Ruesink, 1986). Vectors are first probe on plants hosting viruses and then probe on uninfected pepper plants for the virus to spread within the crop. Aphids are ideal vectors of viruses because successful transmission of viruses requires penetration without excessive injury to plant cells and aphid probe plant cells without causing much disturbance (Shepherd, 1977).

Viruses transmitted by vectors have been classified into three groups based on how long they are retained by the vector and the mechanism by which they are transmitted (Nault, 1997). These categories are: non-persistently transmitted, semi-persistently transmitted and persistently transmitted. The retention period by the vectors are strictly related to the mechanism of transmission. Therefore, non-persistently transmitted viruses are acquired within one minute, infectious directly after gaining and lost after the vectors probes a new host (Sylvester, 1969). The gaining period for semi-persistently transmitted viruses requires minutes, although they can be transmitted shortly after they are acquired. Persistently transmitted viruses are acquired after minutes to hours of feeding, require a latent period before they are transmissible and retained in their vectors where they stay transmissible for weeks. Persistently transmitted viruses are reproducing within and retained during the life of their vectors (Sylvester, 1980).

Both non-persistent and semi-persistent viruses are accepted on the lining of the food canal formed by the stylets, fore gut, and lost as the vector molts (Bos, 1999). Non-persistently transmitted viruses are likely to be detached from the stylets and foregut during long gaining periods and during long probes or feeding (Sylvester, 1969). Such viruses show limited vector specificity within insect families. However, members from more than one insect family will not normally transmit similar viruses (Shepherd, 1977). For example, potyvirus are non-persistently transmitted by different aphid species. *Myzus persicae* is most efficient in transmitting potyvirus in hot peppers (Simon *et al*., 2009). *Myzus persicae* and *Aphis gossypii*

Glover appears equally efficient in transmitting Ethiopian mottle virus (EPMV) from pepper to pepper (Tsedeke, 1988). Alate and apterous aphids of the same species are equally able to transmit any one virus but alate contain the benefit of moving the virus greater distances (Eastop, 1977). The effectiveness of virus transmission by the vector is sometimes affected by the plant from which the virus is acquired (Simons, 1982).

2.7. Managements of Vector Born Viruses

Understanding the epidemiology of vector borne virus is very important to develop suitable management strategies. Simon *et al.* (2009) found greater association between the incidence of EPMV in hot pepper grown in the central rift valley of Ethiopia and vectors. The vectors increased their populations on widespread weeds found in and around hot pepper farms.

2.7.1. Cultural practices

Cultural management of viral disease are a sets of different practices including sanitation which leads to the destruction of alternate hosts which act as sources of infection, crop rotation, intercropping, managing planting date and harvesting time. Destruction of alternate habitats and hosts are intended to remove weeds and wild hosts (Rao *et al.*, 2006). These cultural practices can disturb the life cycle of the virus disease, thereby decreasing its vector population and sources of inoculum. These measures are aimed to eliminating the sources of inoculum within and outside the field and also in reducing the vector population or shifting their feeding behavior. These operations are reducing the numbers of viruliferous insects that reach the crop (Hooks and Fereres, 2006).

Using a good seed source is very important cultural management of plant viruses. Healthy plants are more tolerant to viruses. Crop rotation practices are also help in decreasing the virus disease spread. For example, new vegetables like tomato, pepper and other crops should not be grown nearby old fields having the same or another susceptible crop harboring virus diseases. The incidence of Potato virus Y (PVY) in green pepper is reduced when the crop is grown in fields isolated from other solanaceous crops (Kapooria, 1999).

Planting barrier crops on the edges of fields can help in delaying and/or reducing the increasing of non-persistently transmitted viruses in the field, particularly wherever the aphid vector tends to remain in the area where it first landed. The next viruliferous aphids would drop their virus inoculum to the barrier plants, which they are most likely to probe first. Barrier crops contain a supplementary advantage if they are taller than the field crop because aphids land on taller plants (Broadbent, 1969).

2.7.2. Physical management

Reflective/repelling surface aluminum or plastic mulches have effective primarily against aphid, whitefly and thrips vectors transmitting different viruses. Aphids are responding to various wave lengths of light, the use of attractive colors as traps or repellents to avoid landing of the vector on susceptible crops are important in minimizing the spread of virus diseases (Funderburk, 2009).

Summers *et al*. (2004) reported a comparison competence of spray mulches, film mulches and nets placed on soil surface used to protecting squash from non-persistently transmitted aphid borne viruses. UV reflective aluminum mulches are used to successfully reduce the incidence of aphid borne virus diseases in squash and to delay colonization by *Bemisia argentifolii*

(Summers and Stapleton, 2002). These mulches reflect short-wave UV light, which confuses and repels incoming alate aphids and adult whiteflies, thus reducing their incidence of alighting on plants.

The uses of row cover during the vegetative growth stages of crops can helps to delays and reduces virus incidence. Vectors and viruses are completely barred from pepper with different types of synthetic row cover spending these covers are removed (Farias *et al.,* 1999). According to Espinoza and McLeod (1994) at the end of the growing season, the virus incidence in uncovered plant plots was much greater than in plots that were covered.

2.7.3. Chemical method

Insecticides are often effective against the spread of persistently vector transmitted viruses but not against the spread of non-persistently vector transmitted viruses. Some of the conventional insecticides even increase the incidence of the virus within the crop due to increased probing by agitated vector. Non-persistently vector transmitted viruses are transmitted quickly by the short duration probing less than a minute (Loebenstein *et al*., 2001). The effectiveness of insecticide in controlling non-persistently vectors transmitted viruses also depend on a climatic factors that affected the numbers and movement of the vectors (Pirone *et al*., 1988).

Pyrethroid is one of the types of insecticides quickly knock down the insect vectors like whiteflies, aphids, leafhoppers and thrips. For example, controlling of aphid species likes *Macrosiphum euphorbiae* and *Myzus persicae* by using of pyrethroids are reduced potato virus Y (Loebenstein *et al*., 2001). Pappu *et al*. (2000) have provided the evidence by managing the spread of TSWV in flue cured tobacco by application of acibenzolar-S-methyl and imidacloprid.

Mineral oils are also preventing the transmission of stylet borne viruses without killing the vector or destroying the virus (Simons *et al.,* 1995). Oils avoid aphids from retaining virus particles through gaining and inoculation (Wang and Pirone, 1996). DeWijs *et al.* (1979) reported that the higher viscosity of the oil, the greater its capacity to reduce transmission of stylet borne viruses. An oil coat plant surfaces helps to build up depression between epidermal cells where aphids probe (Simons and Beasley, 1977).

2.7.4. Host resistance

The most successful component of virus disease management is the use of virus resistant varieties. Genetic engineering has allowed for the fast introduction of resistant plant genes as well as virus genes to protect plants against virus infection (Tomlinson, 1987). The successful breeding high yielding varieties of *Capsicum* species including *Capsicum chinense,* which are resistant to potato virus Y, tobacco etch virus, tomato mosaic virus and pepper mottle virus. The performance of a resistant line is dependent on the strain of the virus to which it is exposed to weather, soil conditions and the type of farming practice employed (Villalon, 1981).

Combining resistant crops to vector with some other control measures is very important. For instance, in field trials, rice tungro disease was successfully controlled by a combination of insecticide application and moderate resistance of rice cultivar to the leafhopper vectors (Heinrichs *et al*., 1986). Mung bean germplasm against *Bemisia tabaci* to manage Mungbean yellow mosaic virus spread. Intensive efforts were made for developing crops resistant against whitefly transmitted virus diseases (Kooner and Cheema, 2007). Another example of vector resistance was observed in soybean genotype which are resistant to aphid species such as

Myzus persicae and *Rhopalosiphum maidis* by which Soybean mosaic virus spread was reduced under field conditions (Gunasinghe *et al*., 1988).

2.7.5. Integrated management

Integrated virus disease management is developed by implementation of different control methods like destroying the sources of infections, using of pathogen-free planting material, using of net cover, mulching, using of tolerant cultivars and application of insecticides against vectors (Parvatha, 2009). For example, management of sunflower necrosis disease caused by tomato spotted wilt virus transmitted by thrips was effectively minimized by bordering the sunflower crop with sorghum and sunflower seeds treated with imidacloprid along with spraying the sunflower crop with imidacloprid (Shirshikar, 2008).

Tomato spotted wilt virus (TSWV) in tomato is also successfully managed by the using resistant tomato cultivar and raising the crop in tunnels protected. The thrips vector population was less than the control and yield of tomato cultivar was significantly higher under tunnel cultivation than in open air (Diez *et al*., 1999).

3. MATERIAL AND METHODS

3.1. Field Survey

3.1.1. Description of survey areas

A field survey was conducted in Butajira, Meki and Ziway districts (Table 1), the central rift valley of Ethiopia, where pepper production is very important and irrigation facilities are available during dry season in this district. The locations are characterized by dry sub humid climate and bimodal pattern of rainfall with short rainy season running from February to April and long rainy season from June to September. Butajira has annual rain fall of 1500-1850mm and minimum and maximum temperature of 8°C and 26.5°C, respectively. Meki has annual rain fall of 500-1159mm and minimum and maximum temperature of 12°C and 27.5°C, respectively. Ziway has annual rainfall of 763 to 1000 mm and average minimum and maximum temperature of 15 and 30°C, respectively.

Table 1: Geographic description of study areas

Location	**Altitude**	**Longitude**	**Latitude**
Ziway	1500-2300 m a.s.l	38°01' to 39°30'E	7°15' to 8°30'N
Meki	1636-2200 m a.s.l	38°43' to 39°57'E	7°58' to 8°10'N
Butajira	1500-2131 m a.s.l	38°22' to 38°36'E	8°07' to 8°11'N

The major soil types in central rift valley are sandy loam and sand clay (Kefayalew, 2008). According to FAO soil classification, they have volcanic origin and are described as fluvisol. The areas are very important for horticultural crops production as they have favorable climate and water resource for irrigation.

Farmers in the survey areas practice mixed crop-livestock farming system. The major crops grown in this area include cereals like maize, sorghum, teff, wheat, and barley; pulse crop like field peas, fava beans, and haricot beans; and vegetables like pepper, tomato, onion, cabbage, and potato.

3.1.2. Disease assessment

The field surveys were carried out in 20 fields per district making the total number of surveyed pepper fields 60 across the three districts. Survey was conducted at four different growth stages of pepper namely seedling, vegetative, flowering and podding stages. In each farms, 50 plants were assessed randomly by using quadrant in the form of X Pattern. Farms were visited diagonally in two directions following the X pattern. Data on plant height and number of pods per plant were collected. Disease prevalence was recorded as proportion of fields with diseased plants while disease incidence was recorded as proportion of plants per field showing viral symptoms. In each of the three districts, yellow water traps were set to monitor the aphids' population. The levels of the disease prevalence and incidence were described using descriptive statistics and comparisons were made between locations.

3.2. The Efficiency of Netting on EPMV Transmission

The netting experiment was conducted at Hawassa and Meki. Hawassa is located between 7^o 3' latitude north and 38^o28'longitude east at altitude of 1680 meter above sea level. This area is characterized by dry sub humid climate; it has monthly mean minimum and maximum temperature of 10.4°C and 27.5°C, respectively and annual rain fall of 900-1300mm.

3.2.1. Planting and treatment description

Seedlings of the pepper variety Marekofana which highly is susceptible to EPMV were raised under a protective cover (Figure 1) and sprayed with the systemic insecticide dimethoate (1liter/hectar) weekly to restrict aphids that are vector for EPMV. Pepper seedlings were transplanted to the Hawassa university experimental field and commercial farm field at Meki, when they reached a two leaf growth stages. Experimental plots had a size of 2m x 2m each and the spacing between plant and rows were 0.3m x 0.5m, respectively. The plots and block were spaced one meter apart. A plot contained four rows and each row had six plants, as a result, there were 24 plants per plot. The experiment was laid out in randomized complete block design (RCBD) with three replications consisting of the following treatments: T1: no net barrier (control), T2: pepper covered with net for up to 20 days after transplanting (DAT), T3: pepper covered with net for up to 40 DAT, T4: pepper covered with net for up to 60 DAT, T5: pepper covered with net for up to 80 DAT or until flowering, T6: pepper covered with net until harvesting and T7: weekly spraying of dimethoate 40% EC (1000ml/ha), a contact insecticide, applied at seven days interval.

Figure 1: Pepper growing under netting at Hawassa and Meki

The pepper was grown under irrigation. The recommended rate of DAP (200 kg/ha) and half of the recommended rate of urea (100 kg/ha) fertilizers were applied in bands at the time of transplanting. The remaining half rate of urea was applied during active stage of vegetative growth (EARO, 2004). All other recommended cultural practices were performed uniformly to all plots as per the recommendation.

3.2.2. Data collection

3.2.2.1. Monitoring of aphid populations in experimental field

Aphids were monitored by using Yellow Water Traps (YWT) that was made from yellow plastic container with size of 10x35x20cm (Figure 2). One YWT was placed in the middle of each plot one week after transplanting of pepper plants. The traps were filled with water up to small outlets below the rim. The heights of the traps were adjusted according to the crop canopy. Five milliliter of formaldehyde was added in the water of each trap to keep the aphids intact and prevent birds from drinking the water. Every week, the solution in YWT was changed and trapped aphids were collected until the pepper crop fully matures. The collected aphids were counted according to date of collection and treatments. The data was summarized to investigate the population of aphids in relation to the crop phenology.

Figure 2: Aphid monitoring using yellow water trap

3.2.2.2. Incidence of Ethiopian pepper mottle virus

Starting 20 days after transplanting, all pepper plants in each plot were visually assessed for the incidence of EPMV infection caused by natural infestation special aphids infestation. Well established symptoms based evaluation method for EPMV was used for rating of the incidences (Tameru, 2004; Marame *et al*., 2010). Ethiopia pepper mottle virus incidence on each experimental treatment was recorded by counting number of diseased plants and calculating as the proportion of the diseased plant over the total number of stand count per treatment.

3.2.2.3. Growth parameters

Up on harvesting of pepper plants, data on the growth parameters of pepper were recorded as follows:

Plant height (cm): Plant height measurement was made from the soil surface to the top growth points of above ground plant part. The measurement was taken from eight plants of each central row per plot.

Number of branches per plant: Numbers of primary, secondary and tertiary branches per stem of randomly selected eight middle row plants.

Leaf canopy cover: The mean values were taken by measuring diameter of the plant (north to south and east to west dimension of the above ground part of eight sample plants per plot).

3.2.2.4. Marketable yield and unmarketable yield

Pepper pods were harvested from the inner two rows of each plot, and the pods were sorted into marketable and unmarketable pods based on the presence or absence of green mottling, swelling, color, and shape deformation. Weights of marketable, unmarketable and total fruit were measured.

Marketable yield (q/ha): The marketable yield of eight sample plants per plot was determined at harvesting by sorting fruits according to color, shape, shininess, firmness and size of the fruits. After separation the weight of marketable fruits were recorded and converted to q/ha.

Unmarketable yield (q/ha): The yield which was obtained by sorting the diseased, discolored, shrunken, shaped and small size, totally un necessary pod separated from marketable pods were recorded at harvest and converted to q/ha.

Total yield (q/ha): Weight of total marketable and unmarketable fruits harvested from each sample plants were recorded and summed up to estimate yield per hectare.

3.2.3. Data Analysis

Data on aphid populations, viral incidence, growth parameters and yield were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures of SAS version 9.00, (SAS Institute, 2002). Whenever treatment differences were significant, the differences among treatment means were compared using Tukey's LSD test at 5% level of significance. Correlation analysis was carried out by using proc corr procedure of simple Pearson correlation to assess the relationship between aphid populations, disease incidence, growth parameters and yield.

4. RESULTS AND DISCUSSION

4.1. Field Survey

Virus disease-like symptoms characteristic including severe reduction of leaf size, curling, crinkling of interveinal areas, interveinal and marginal chlorosis, occasional development of venations, shortening of internodes, sunting or dwarfing, development of small branches, bright yellow spot on leaves and reduced fruiting were observed in pepper fields across surveyed fields in Butajira, Meki and Ziway (Figure 3).

Figure 3: Pepper plants showing EPMV disease symptom

4.1.1. Prevalence of EPMV

The prevalence of EPMV ranged from 95 to 100% at Ziway, while it was 100% in Meki and Butajira districts (Table 2). Tameru (2004) also reported 100% potyvirus in rifty valley area of Ethiopia. The high level prevalence of potyvirus in pepper could be attributed to a number of factors such as climatic condition, presence of alternate host and vector activity (Fajinmi, 2006).

In our survey areas, pepper is grown almost all the year round using irrigation ensuring continuous presence of the main host to the pathogen and its vectors. Besides, alternate hosts like *Datura stramonium* and *Nicandra physaloides* are available in and around pepper farms and they fill the host gap during the short period, when pepper is not grown in the field. In addition, the relatively warm and dry conditions in the survey areas are suitable for aphids that serve as important vectors of the EPMV.

4.1.2. Incidence of EPMV

The mean incidence of EPMV in the surveyed districts was 60.6%, 52.8% and 69.5% at Meki, Ziway and Butajira, respectively, (Table 2). The highest mean incidence (87%) was recorded at Abeshge kebele followed by Meskan kebele (76 %). Both areas are located in Butajira district. On the other hand, the lowest disease incidence (38 %) was recorded at Elka Calamo kebele in Ziway district. Tameru (2004) reported poty virus incidence of 89 % in Hawassa and 15 % in Meki area in an earlier work. This suggested an increase in viral incidence in Meki by several folds over the past 15 years.

High incidence of viruses on pepper might be related to the presence of numerous alternative host species such as tomato, potato, cabbage and cucurbits and also weed species like *Datura stramonium* and *Nicandra physaloides* around the pepper field. Fajinmi (2011) also reported that ecological characteristics, climate and vegetation in the diverse ecological zones appeared to play a major role in determining the incidence of virus infection on pepper in the field.

Table 2: Prevalence and incidence of EPMV in pepper fields

Zone	Districts	Kebele	Prevalence (%)	Incidence (%)	Ranges of incidence (%)
East shewa	Meki	Girisa	100	54±1.78	40-60
		Bakale	100	50±2.65	25-65
		Korke Adi	100	69±2.49	45-80
		Choroke	100	57±1.72	20-85
		Meto Arba	100	73±0.94	40-85
	Mean		**100**	**60.6±1.91**	**34-75**
	Ziway	Edo Gojola	100	60±2.45	20-75
		Abossa	100	45±1.99	10-75
		Dodicha	100	70±3.60	30-90
		Garbi Boramo	95	51±2.83	0-70
		Elka Calamo	100	38±3.10	15-60
	Mean		**99**	**52.8±2.79**	**15-74**
Gurage	Butajira	Meskan	100	76±1.29	30-90
		Mareko	100	52±1.10	25-65
		Gedebano	100	63±2.15	20-90
		Abeshge	100	87±1.76	40-95
	Mean		**100**	**69.5±1.57**	**28.75-85**

4.1.3. Incidence of EPMV on pepper at different growth stages

Ethiopian pepper mottle virus was evident on pepper plants starting from seedling stage but their level increased as the pepper plants grew older (Figure 4). Generally, disease incidence increased by at least two fold from seedling to pod stage across the locations. At the seedling stage, disease incidence was highest in Butajira and the lowest in Ziway area. Results of the current survey revealed that EPMV incidences were higher in Butajira by 68 % and 30 % as compared to those in Ziway and Meki, respectively. At vegetative stage disease incidence was the highest at Meki district followed by Butajira and Ziway.

Symptoms of EPMV appeared in the surveyed fields have association with the availability of alternative host and vector infestation as well as environmental factors. Early infected pepper plants have low level of resistance as compared to late infected plants. The intensity of symptoms appeared in the early infected pepper might be confirmed that infection at early growth stage was more destructive than late infection of pepper plants by EPMV. Fajinmi (2011) also reported that alternative host present in different ecological zone can affect the incidence of potyvirus on pepper plants in the field.

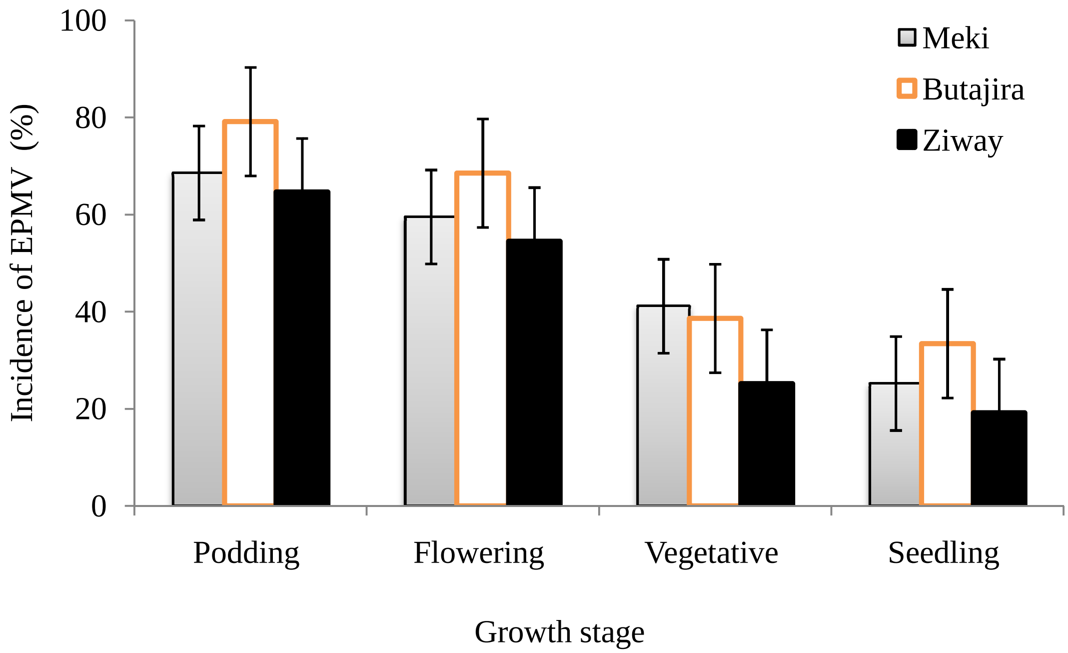

Figure 4: Incidence of EPMV at different growth stages of pepper

4.1.4. Abundance of aphids in pepper field

During field surveys a total of 1,237 aphids were collected from Butajira, Ziway and Meki by using yellow water traps. Out of the total collected aphids, 39.6% were from Butajira, 31.9% from Meki and 28.5% from Ziway (Figure 5). Alate aphids were more dominant in Butajira district as compared to Meki and Ziway. The presence of aphids in larger numbers in Butajira then in Meki and Ziway districts could be one contributing factor for higher EPMV incidence in the farmer field. Higher aphid population in Butajira might be due to the presence of more cultivated crop species and alternative hosts. This finding is in agreement with the work of Simon *et al*. (2009) and Marame *et al*. (2010), who indicated the relationship between the abundance of aphids and the presence of different host plants in and round the pepper field.

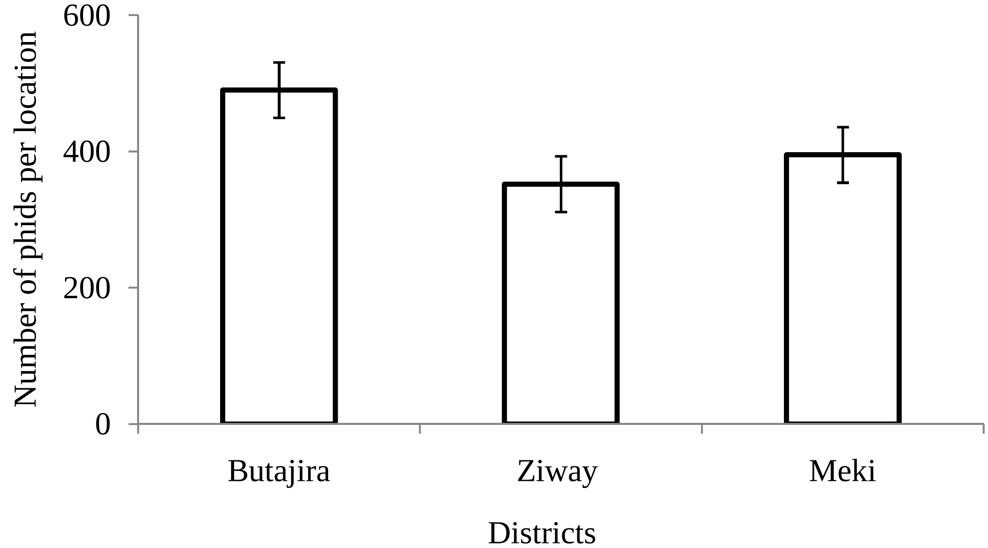

Figure 5: Abundance of aphids per trap in survey area

4.1.5. Pod number and plant height

The highest overall mean number of pods and plant height was recorded from Ziway district followed by Meki whereas the lowest was recorded from Butajira district (Figure 6). As compared to Butajira and Meki districts the number of pods in pepper fields of Ziway was higher by 23% and 17%, respectively, while plant height increased by 26% and 23%, respectively. This was due to higher virus pressure at Butajira and Meki than Ziway starting from early growth stages of pepper.

In Butajira district the height of pepper plants were radically reduced as a result of EPMV infection. This result might be due to more abundance of vectors and alternative hosts were present in Butajira district than Meki and Ziway. Taiz and Zeiger (2010) reported that severe cucumber mosaic virus symptoms inhibited plant growth by obstructing the flow of water to the adjacent elongating cells from the xylem. (Mushtaq *et al*., 2014) also indicated that plant height is attained through cell enlargement, division and differentiation, which are most susceptible to physiological processes in stressed condition being expressed in diseased plants

Fruits of pepper crops were higher in Ziway district than Butajira and Meki districts. This might be related to the infection of EPMV and infestation of aphids in that area. Podding was delayed in the more infected district as compared to less infect district, most likely as a result of virus host plant interaction. This was due to infected pepper crops have expended more time and energy to overcome the stress imposed by the pathogen. Herms and Mattson (1992) reported that the stresses imposed by potyvirus could induce a complex cellular and molecular response system to prevent damage and ensure plant survival.

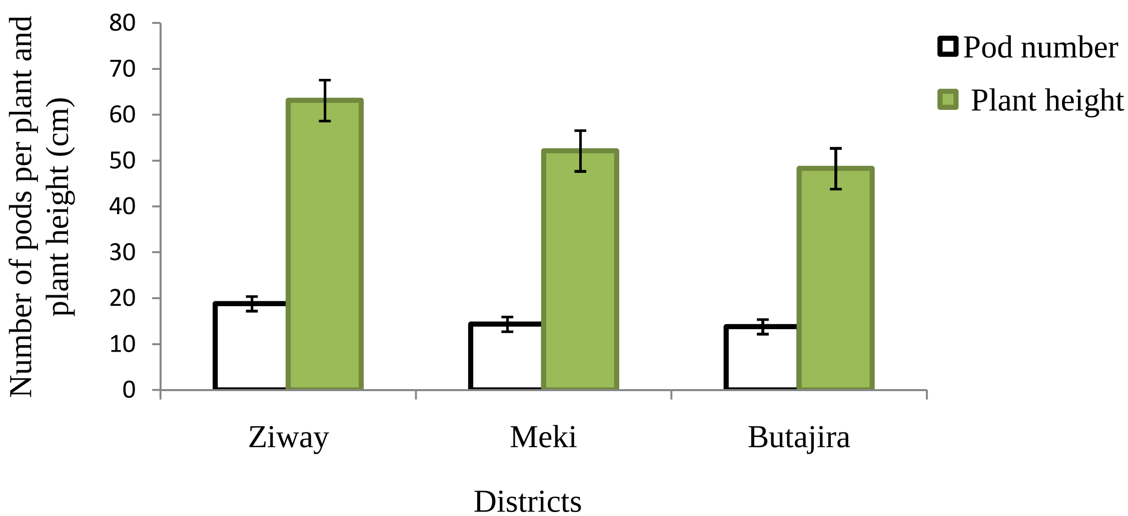

Figure 6: Effect of EPMV on number of pods per plant and plant height

4.2. Field experiment

The results from the present study showed that the incidence of Ethiopian pepper mottle virus could be affected by using nets to protect vectors (aphids). The analysis of variance revealed significant differences among treatments with respect to vegetative growth parameters, incidence of virus, aphid population, marketable and unmarketable yield.

4.2.1. Incidence of Ethiopian pepper mottle virus

EPMV disease was first observed on control plots and weekly spraying with insecticide plots at both locations during the first assessment (5/9/2017 in Hawassa and 2/10/2017 in Meki) (Figs. 7 and 8). However, significant differences in terms of disease incidence across treatments appeared during the second assessment (22/10/2017) and third assessment (15/10/2017) after planting at Meki and Hawassa, respectively.

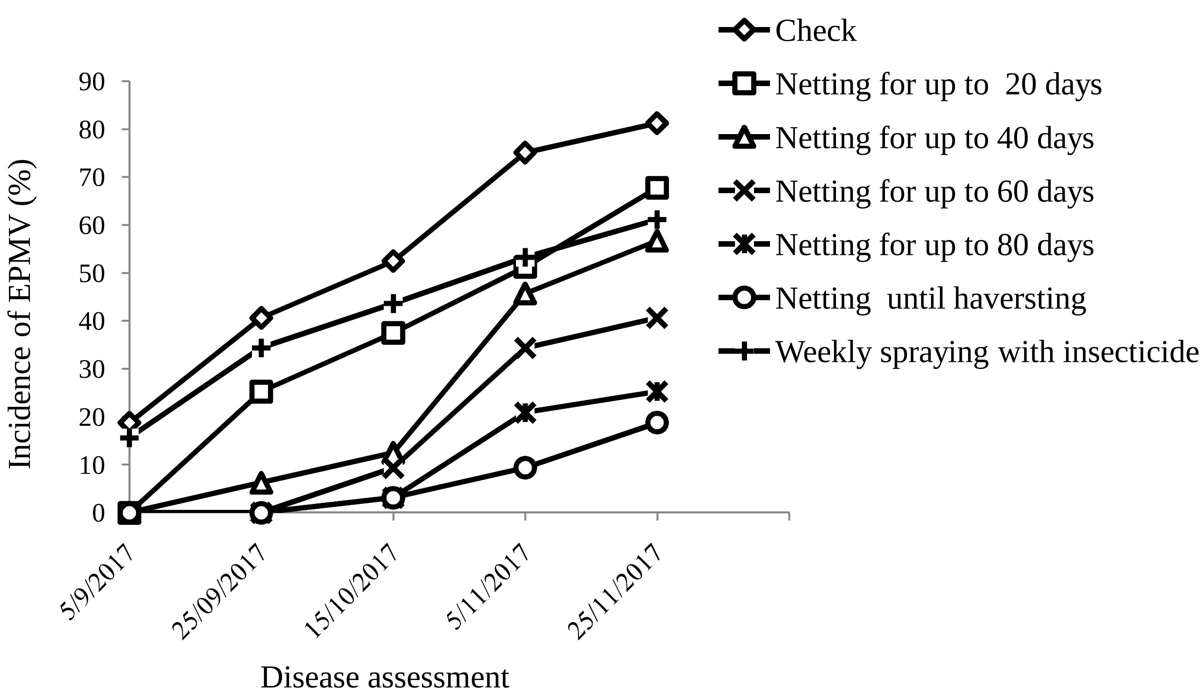

Figure 7: Effect of netting duration on EPMV at Hawassa

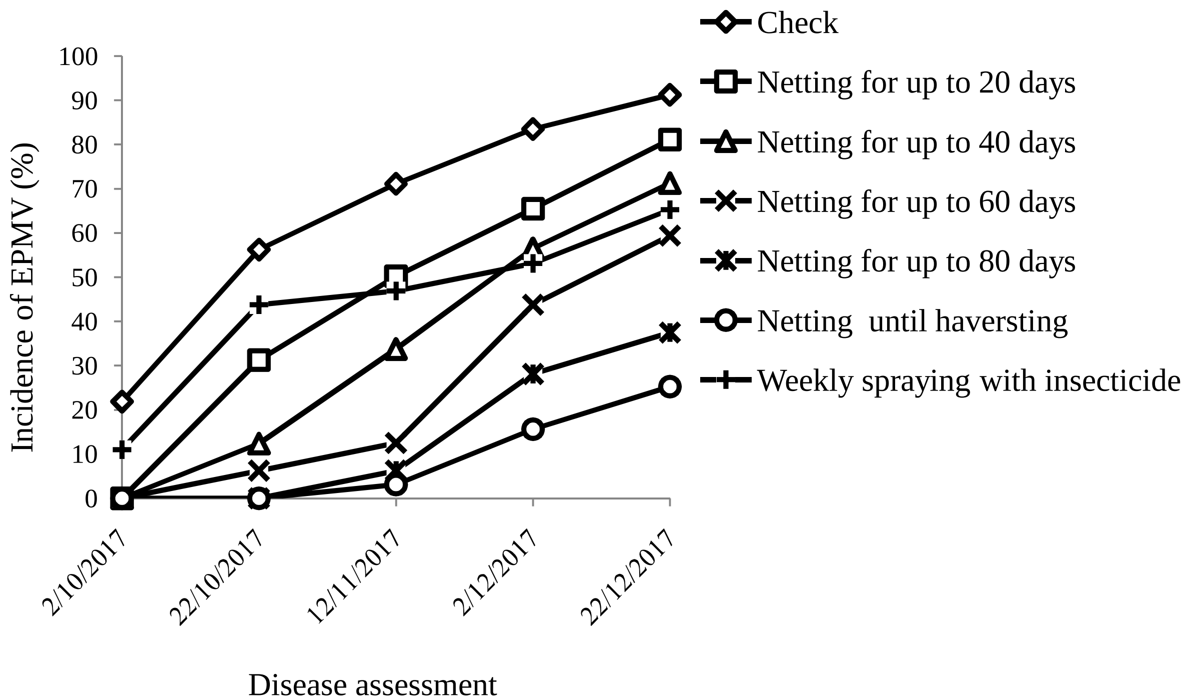

Figure 8: Effect of netting duration on EPMV at Meki

Overall disease incidence was high in Meki as compared to Hawassa. This might be due to the presence of several hosts for the vectors in and around the experimental field in Meki. The results are consistent with the finding of DiFonzo *et al*. (1997), who reported rapid spreading of viruses in particular area associated with the presence of vectors and hosts. Simon *et al*. (2009) also reported increasing of virus with a large diversity of crop species cultivated and weed species in and around field. Similarly, Nault *et al*. (2004) reported the infection of Cucumber Mosaic virus (CMV) in Alfalfa was greatly associated with dispersal of aphids from nearby Snap Beans.

Analysis of variance indicated highly significant difference ($p<0.01$) in virus incidence across treatments at both locations (Appendix Tables 1 and 2). The lowest EPMV incidence (22.5 %

at Hawassa and 32.5 % at Meki) was recorded from the pepper plants covered by net until harvesting (Table 3). On the other hand, the highest mean EPMV incidence (57.5 % in Hawassa and 63.12 % in Meki) was recorded from uncovered plots. Therefore, netting until harvesting was considered the most effective in reducing viral incidence. In a previous work, Olabode *et al*. (2007) reported aluminum mulching as effective measure in reducing virus incidence.

Table 3: Effect of nets on aphids per plant, average disease incidence and final disease incidence

Treatment	Aphids per plants ± SE		Average disease incidence ± SE		Final disease incidence ± SE	
	Hawassa	Meki	Hawassa	Meki	Hawassa	Meki
Uncovered	40.50± 1.72[a]	45.21±0.91[a]	57.50±1.30[a]	63.12±1.19[a]	81.25±2.60[a]	87.50±0.50[a]
Netting for up to 20 days	27.75± 1.97[b]	39.37±0.34[ab]	43.75±1.25[ab]	52.50±1.04[b]	71.87±2.12[ab]	78.12±0.13[ab]
Netting for up to 40 days	17.93± 0.87[c]	25.90±2.06[bc]	34.97±1.39[bc]	42.50±1.02[cd]	51.37±1.05[cd]	65.62±1.10[cd]
Netting for up to 60 days	17.37± 1.34[c]	21.56±0.52[bc]	29.87±1.83[bc]	38.75±1.25[de]	40.62±1.12[de]	59.37±2.12[d]
Netting for up to 80 days	13.06± 0.65[c]	18.31±1.03[c]	24.37±0.62[c]	35.00±1.04[de]	37.50±0.24[de]	43.75±1.60[e]
Netting until harvesting	10.50± 0.47[c]	14.90±1.27[c]	22.50±0.33[c]	32.50±1.06[e]	34.37±1.13[e]	40.62±1.12[e]
Spraying with insecticide	30.81± 0.19[b]	37.37±2.71[ab]	48.12±1.60[ab]	49.37±1.19[bc]	66.25±2.60[bc]	75.00±0.25[bc]
LSD (0.05)	8.87	17.84	18.64	9.11	14.92	12.20
CV (%)	15.92	26.37	21.39	8.69	11.66	8.12

Where, CV=coefficient of variation; LSD=least significant difference; SE= standard error; means in a column followed by the same letter are not significantly different at $p<0.05$.

4.2.2. Aphids population per plant

No aphid was caught during the first samples except in control plots and weekly spraying with insecticide at both locations. On other hands, plots covered by net for up to 20 days have started to show aphid infestation during third and second sampling at Hawassa and Meki, respectively (Figs. 9 and 10). In most treatments, the number of aphids' catches decreased during sixth and fifth weeks at Hawassa and Meki, respectively. This may be related to rainfall conditions and existence of diverse host plants in the fields. Generally, infestations of pepper plants by aphid were lower in plots covered by net for longer times as compared to control plots at both locations.

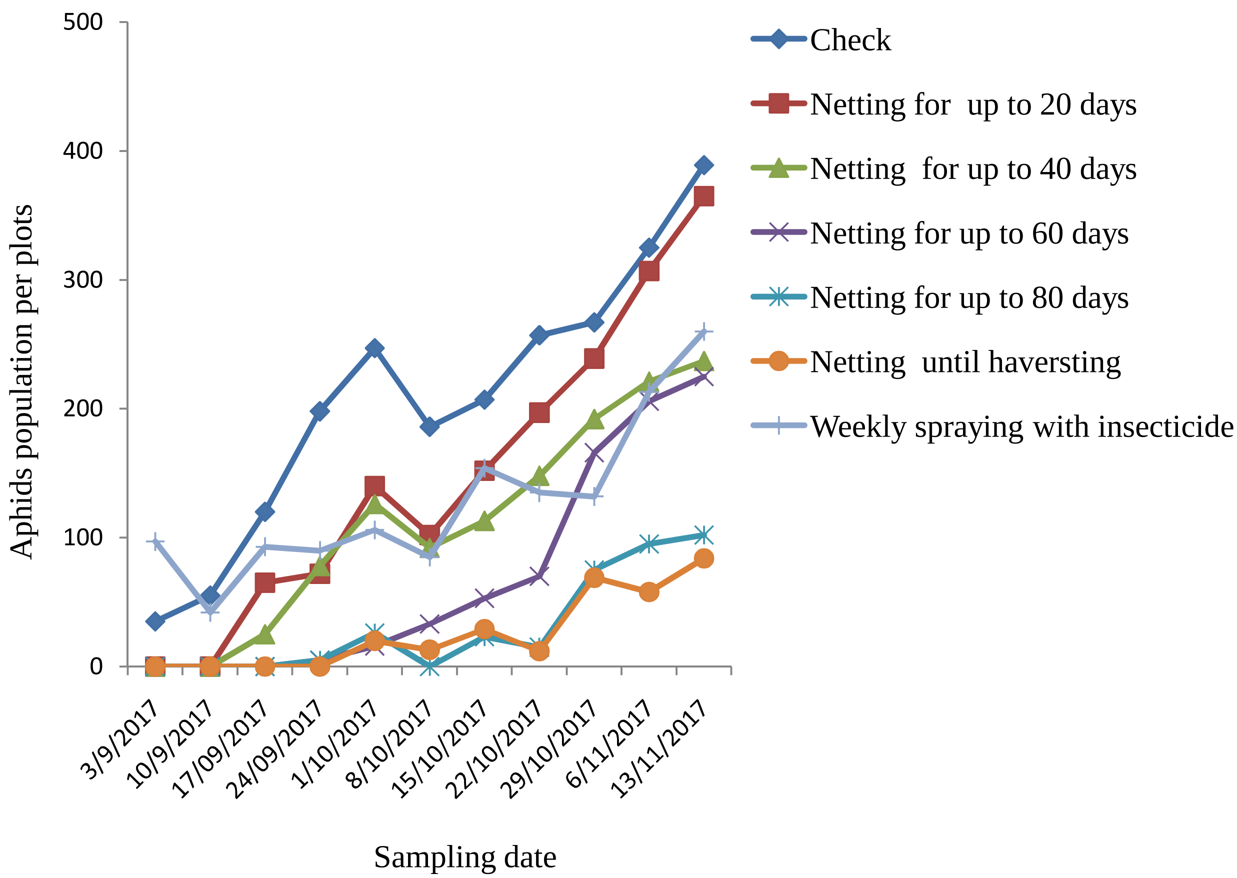

Figure 9: Effect of netting duration on aphid vectors dynamics per trap at Hawassa

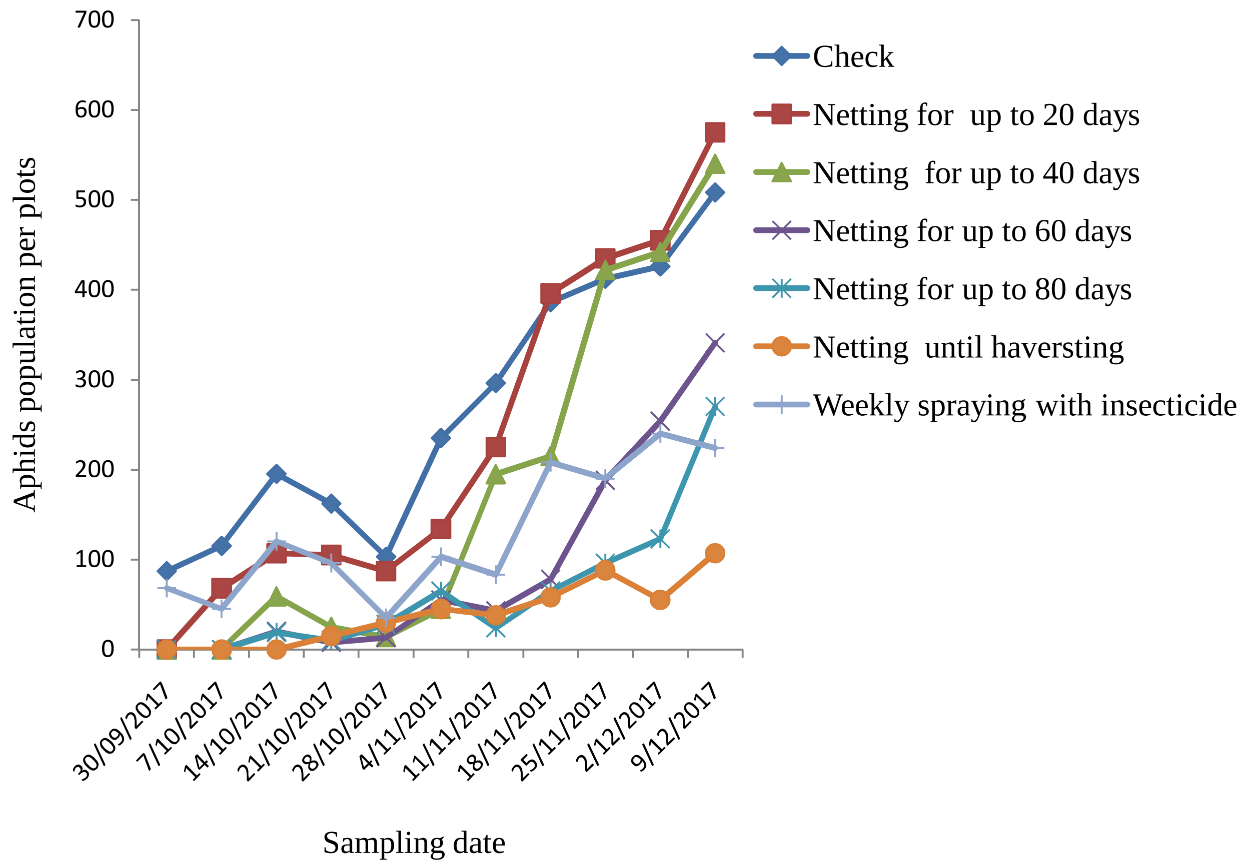

Figure 10: Effect of netting duration on aphid vectors dynamics per trap at Meki

Aphids were more abundant at Meki as compared to Hawassa. This might due to the presence of many hosts in and around pepper fields and environmental condition in Meki area. This result agrees with DiFonzo *et al.* (1997), who reported the positive role of several cultivated crops and volunteer plants in increasing the population of aphids in potato farms in the same region. Similarly, Simon *et al*. (2009) reported that population of aphid species was high in the presence of large diversity of crop species cultivated.

The mean number of aphids per plant across treatments at both locations were significantly different ($p<0.01$) (Appendix Tables 1 and 2). Plots covered by net until harvesting and up to 80 days after transplanting were consistently significantly different from plots of other treatments in reducing the aphid population regardless of the location. On the other hand, the significance reduction in aphid population was varied depending on the location when plots were covered with nets only up to 60 days after transplanting (Table 3).

The highest mean number of aphids per plants (40.5 in Hawassa and 45.21 in Meki) was recorded from control plots while the lowest mean of aphids per plants (10.5 in Hawassa and 14.9 in Meki) was recorded from plots covered by net until harvesting. As compared to the control plots, the mean number of aphids per plant was reduced by 74% at Hawassa and 67% at Meki, when plots were covered by net until harvesting. On other hand, covering plots by net for up to 80 days after transplanting has reduced mean number of aphids per plant by 67.8% and 40.5% at Hawassa and Meki, respectively, as compared to the unprotected plots (Table 3).

4.2.3. Effect of netting duration on growth performance of pepper plants

4.2.3.1. Number of branches per plant

The mean number of branches per plant was highly significantly ($p<0.01$) influenced by netting duration at Hawassa while it was not significantly different across treatments at Meki (Appendix Tables 3 and 4).

The netting duration has increased the number of branches per plant (Table 4). The highest mean number of branches per plant was recorded from plots covered by net until harvesting and netting up to 80 days after transplanting. On the other hand, the lowest mean number of branches per plant was recorded from plots without netting and plots covered by the net for up to 20 days followed by weekly spraying with insecticide. Pepper plants grown under netting until harvesting and up to 80 days after transplanting had 58% and 46.9% more branches, respectively, than those plants without netting (Table 4). Pazarla *et al*. (2013) reported 42 to 69 % increase in branch number when pepper plants were infected at latter growth stages than early growth stages.

4.2.3.2. Plant height

Analysis of variance revealed that netting durations had significantly different ($P<0.01$) effect on plant height at both locations (Appendix Tables 3 and 4). Plots covered by net until harvesting and up to 80 days after transplanting were significantly different from the other plots at Hawassa while it was not significantly different from plots covered by net for up to 60 days and 40 days after transplanting at Meki (Table 4). The highest mean plant height (71.31cm in Hawassa and 51.60cm in Meki) was recorded from plots covered by net until harvesting. On the other hand, the lowest mean plant height (44.19cm in Hawassa and 42.71cm in Meki) was recorded from control plots. This result may have been related to the protecting of early infestation of vectors and virus infection. In addition to protecting vectors and viruses, nets are also used to promote rapid plant growth by creating favorable conditions of soil temperature and moisture and resulting in better uptake of nutrients (Tindall *et al*., 1990; Olobashola *et al*., 2017).

As compared to control plants, plant height was increased by 20.8% at Meki and 61.4% at Hawassa, when they grew under net up to harvest. Similarly, plants covered by net up to 80 days after transplanting has increased plant height by 17.5% at Meki and 60.6% at Hawassa (Table 4). In another study, Olobashola *et al*. (2017) reported that plant height of okra was increased with using of aluminum mulch as compared to un-mulched.

4.2.3.3. Leaf canopy cover

The analysis of variance showed that there was a significant difference ($p<0.05$) in canopy cover between treatments at Hawassa while the effect was highly significantly different ($p<0.01$) at Meki (Appendix Tables 3 and 4).

The highest mean leaf canopy cover (43.15cm in Hawassa and 37.47cm in Meki) was obtained from the plots covered by net until harvesting; while, the lowest (35.21 cm in Hawassa and 29.10 cm in Meki) was obtained from control plots followed by weekly spraying with insecticide (Table 4). This variation in leaf canopy cover might be due to nets protecting early infestation of vector and virus infection. Agrios and Walker (2005) reported increased in leaf diameters when pepper plants were infected by viruses at latter growth stage.

The plants that grew under netting until harvesting after transplanting had 22.6% and 28.4% more canopy than control plants at Hawassa and Meki, respectively. Wider canopy cover can result in the production of more fruits than narrow leaf canopy cover due to increase in a number of secondary and tertiary branches. Aliyu *et al*. (2002) also reported plants with large crown produced more yield than plants with small crown.

4.2.3.4. Number of pods per plant

The mean number of pods per plants revealed highly significant ($P<0.01$) difference across treatments at both locations (Appendix Tables 3 and 4). The highest mean number of pods per plants was obtained from plots covered by net until harvesting and up to 80 days after transplanting. On the other hand, the lowest mean number of pod per plants was recorded from plots without netting and plots covered by net for up to 20 days at both locations (Table 4).

The late infected pepper crops have produced significantly more and longer fruits than early infected plants. This might be due to combined effects of poor growth and high incidence of EPMV at early growth stage. As compared to un covered plots, plants covered by net until harvesting have produced 50 and 31 % more fruits at Hawassa and Meki, respectively, while pepper plants grown in plots covered by net up to 80 days after transplanting produced 19 and 15 % more fruits at Hawassa and Meki, respectively. The increasing effects of early infection on pepper plants have resulted in poor yield and severe yield losses at harvest. Damiri (2014) also reported 42-38 % decrease in the number of pods per plant, when plants were infected at a growth stage of 15, 65 and 90 days after planting. Similarly, Avilla *et al*. (1997) reported the reduced number of pods per plant when pepper plants were infected by cucumber mosaic virus and/ or potato virus y at different age.

Table 4: Effect of netting duration on plant height, leaf canopy cover, number of pod per plant and number of branches

Treatment	**PH (cm) ± SE**		**LCC (cm) ± SE**		**NPP ± SE**		**NBP ±SE**	
	Hawassa	Meki	Hawassa	Meki	Hawassa	Meki	Hawassa	Meki
Uncovered	44.19±0.46^{d}	42.71±0.29^{c}	35.21±0.61^{b}	29.10±0.47^{d}	20.71±1.78^{d}	20.68±0.44^{b}	10.56±1.41^{c}	10.91±0.78
Netting for up to 20 days	51.75±1.10^{bc}	43.71±0.63^{bc}	35.59±1.10^{b}	32.79±0.37^{cd}	21.06±2.65^{d}	20.81±0.44^{b}	11.62±0.88^{bc}	11.28±0.44
Netting for up to 40 days	53.21±0.67^{b}	47.64±0.60^{ab}	36.68±2.60^{ab}	36.21±1.58^{abc}	22.06±2.49^{dc}	22.15±0.94^{ab}	14.28±0.99^{ab}	12.28±0.50
Netting for up to 60 days	53.54±0.47^{b}	49.12±0.77^{a}	43.06±1.76^{a}	36.71±0.90^{ab}	25.78±1.72^{abc}	22.43±1.20^{ab}	14.93±0.80^{ab}	12.81±0.40
Netting for up to 80 days	70.97±0.43^{a}	50.17±0.56^{a}	42.57±1.00^{a}	37.47±0.63^{a}	27.18±0.94^{ab}	23.81±1.49^{a}	16.12±1.41^{a}	13.81±0.59
Netting until harvesting	71.31±0.79^{a}	51.60±0.33^{a}	43.15±0.15^{a}	37.47±1.57^{a}	30.28±2.45^{a}	24.62±0.51^{a}	16.65±1.55^{a}	13.28±0.42
Spraying with insecticide	45.98±1.29^{cd}	43.30±0.91^{bc}	38.92±2.15^{ab}	33.56±1.03^{bc}	23.25±0.70^{bcd}	21.09±0.51^{b}	13.50±1.32^{abc}	11.46±0.57
LSD (0.05)	7.04	4.81	6.61	3.90	2.99	2.47	3.44	2.94
CV (%)	5.39	4.39	7.19	4.80	8.15	4.76	10.56	10.26

*Where, **CV**=coefficient of variation; **LSD**= least significant difference; **NBP**=number of branches per plant; **PH**= plant height per plant; **LCC**= leaf canopy cover; **NPP**= number of pods per plant; SE= standard error; means in a column followed by the same letter are not significantly different at p<0.05.*

4.2.4. Effect of netting duration on yield

4.2.4.1. Marketable yield

Netting duration had a highly significant ($P<0.01$) effect on marketable yield of pepper at both locations (Appendix Tables 5 and 6). Plots covered by net until harvesting and up to 80 days were significantly different in terms of marketable yield from plots without netting, covered by net for up to 20 days and weekly spraying with insecticide at both locations (Table 5). Highest mean marketable yield was harvested from plots covered by net until harvesting and up to 80 days followed by netting up to 60 days after transplanting. On the other hand, the lowest mean marketable yield was harvested from control plots and plots covered by net for up to 20 days after transplanting at both locations. Variation was might be due to reduction of virus infection and vectors infestation. This finding agree with Fajinmi and Odebode (2010), who indicated that increased in fruit yield and quality was achieved with a reduction of diseased plant by controlling of pepper veinal mottle virus.

As compared to control plots, marketable yield was increased by 49 % and 48% at Meki; 55 % and 51% at Hawassa when plants were covered by net until harvesting and covered by net for up to 80 days after transplanting, respectively (Table 5). Avilla *et al*. (1997) also indicated 20 to 80 % increased in marketable yield when plants were infected by potyvirus at latter growth stage.

4.2.4.2. Unmarketable yield

The result revealed that netting duration had a significant **(**$P<0.01$) effect on the unmarketable yield (Appendix Tables 5 and 6). Control plots were significantly different from plots covered by net for up to 40 days and longer at Hawassa while it was significantly different from plots covered by net for up to 60 days and more at Meki (Table 5). The highest mean unmarketable yield (1.53 q/ha in Meki and 1.08 q/ha in Hawassa) was recorded from control plots. On the other hand, the lowest mean unmarketable yield (0.27 q/ha in Meki and 0.11 q/ha in Hawassa) was recorded from plots covered by nets until harvesting and covered by net for up to 80 days after transplanting, respectively (Table 5). Ong *et al*. (1984) and Meyers *et al*. (1998), reported 50-60 % yield reduction of pepper plants due to the infection of potyvirus.

In this study it was observed that unmarketable yield decreased with increasing in net cover duration. This might be due to nets protecting aphids infestation at early growth stage and physiological disorders (bleaching) during the fruit set or the climatic conditions of the growing environment. As compared to control plots, plots covering plants by nets up to 80 days after transplanting or until harvesting reduced unmarketable yields by 80-89% at Hawassa and 75-82% at Meki (Table 5). This finding was agreement with Fuchs and Mainzenmeayers (1999), who reported greater than 25 % reduction in cotton fruit yield when crops with higher incidence of potyvirus. Similarly, Mukasa et al. (2003) reported up to 98% decrease in yield when sweet potato plants were infected by sweet potato feathery mottle virus at latter growth stages than early growth stages.

4.2.4.3. Total yield

Netting duration had a highly significant ($P<0.01$) effect on total yield of pepper at both locations (Appendix Tables 5 and 6). Generally, the highest mean total yield was harvested from plots covered by net until harvesting and up to 80 days followed by covered by net for up to 60 days while the lowest total yield was harvested from plots without netting and covered by net for up to 20 days after transplanting at both locations (Table 5). This result agrees with Agrios and Walker (2005), who reported increased in growth and yield when pepper plants were infected at latter growth stage.

As compared to control plants (no netting), pepper plants from plots covered by net until harvesting and up to 80 days after transplanting gave 39-43% and 32% more yield at Hawassa and Meki, respectively (Table 5). Tameru *et al*. (2003) also reported greater than 90 % yield loss and complete pepper plants failure in Ethiopia by potyvirus genus special Ethiopian pepper mottle virus and potato virus y. Avilla *et al*. (1997) found similar effects of virus on total weight and marketable weight of fruit produced by pepper plants infected at different stage of development.

Table 5: Effect of netting duration on marketable, unmarketable and total yield

Treatment	Marketable yield (q/ha) ±SE		Unmarketable yield (q/ha) ± SE		Total yield (q/ha) ± SE	
	Hawassa	Meki	Hawassa	Meki	Hawassa	Meki
Uncovered	11.45±0.80^{d}	10.33±0.96^{c}	1.08±0.27^{a}	1.53±0.24^{a}	12.53±0.77^{c}	11.86±0.68^{c}
Netting for up to 20 days	11.99±0.49^{cd}	10.75±2.07^{bc}	1.06±0.18^{a}	1.26±0.18^{ab}	13.05±0.40^{c}	12.01±0.89^{c}
Netting for up to 40 days	16.10±0.69^{abc}	13.10±0.87^{ab}	0.39±0.16^{ab}	1.16±0.19^{abc}	16.50±0.82^{abc}	14.26±0.24^{abc}
Netting for up to 60 days	16.51±1.61^{ab}	14.26±1.93^{a}	0.23±0.06^{b}	0.64±0.24^{bcd}	16.74±1.57^{abc}	14.91±0.99^{ab}
Netting for up to 80 days	17.30±1.10^{a}	15.33±1.74^{a}	0.11±0.03^{b}	0.37±0.14^{cd}	17.42±1.08^{ab}	15.71±0.74^{a}
Netting until harvesting	17.75±0.92^{a}	15.45±2.03^{a}	0.21±0.05^{b}	0.27±0.11^{d}	17.96±1.90^{a}	15.72±0.94^{a}
Spraying with insecticide	12.14±0.56^{bcd}	11.48±1.05^{bc}	0.97±0.02^{a}	1.41±0.20^{ab}	13.12±0.53^{bc}	12.90±0.66^{bc}
LSD (0.05)	4.38	2.73	0.71	0.88	4.29	2.68
CV (%)	12.7	9.03	52.92	39.54	11.99	8.24

Where, CV=coefficient of variation; LSD=least significant difference; SE=standard error, means in a column followed by the same letter are not significantly different at $p<0.05$.

4.2.5. Correlation between disease, vectors and yield

Correlation analysis among disease and growth parameters revealed the negative impacts of virus on pepper quantitative and qualitative yield except unmarketable yield which was positively influenced by disease and vectors at both locations (Tables 6 and 7). This result is in agreement with Tameru (2004), who reported reduction in pepper pod yield due to potyvirus.

In general, there was positive and highly significant ($p<0.001$) correlation between virus incidence, aphids population and unmarketable yield. This finding is in agreement with Fajinmi *et al*. (2011), who reported that aphids' distribution within a particular area has a significant contribution in transmitting viral diseases that subsequently lead to yield losses.

Marketable yield and total yield were negatively correlated with virus incidence and aphids' population while they were positively correlated with growth parameters (plant height, leaf canopy cover and number of branches) at both locations (Tables 6 and 7). Increasing disease incidences and vectors can cause significant reduction in the yields. Fajinmi and Odebode (2010) reported that the yield of pepper was negatively correlated with pepper veinal mottle virus and vectors.

Table 6: Correlation among disease, vectors, growth parameter and yield at Meki

	BN	PH	LCC	POD	MY	UMY	TY	INC	APH
BN	1.0000								
PH	0.6273***	1.0000							
LCC	0.5206**	0.7953***	1.0000						
POD	0.5076**	0.7695***	0.6323***	1.0000					
MY	0.5599**	0.6665***	0.7079***	0.6064***	1.0000				
UMY	-0.5215**	-0.6794***	-0.5536**	-0.7220***	-0.7219***	1.00000			
TY	0.5152**	0.5965***	0.6817***	0.5130**	0.9801***	-0.5704**	1.0000		
INC	-0.5500**	-0.7530***	-0.8771***	-0.7142***	-0.7957***	0.6832***	-0.7487***	1.0000	
APH	-0.4758*	-0.7772***	-0.7014***	-0.6046***	-0.5595**	0.6880***	-0.4670*	0.5241***	1.0000

*Where, *=p<0.05, **=p<0.01 and ***=p<0.0001*

***BN**= branch number; **PH** =plant height; **LCC**=leaf canopy cover; **POD**= pod number; **MY** =marketable yield; **UMY** =unmarketable yield; **TY**=total yield; **INC**= viral incidence; **APH**= aphids population per plant.*

Table 7: Correlation among disease, vectors, growth parameter and yield at Hawassa

	BN	PH	LDC	POD	MY	UMY	TY	INC	APH
BN	1.00000								
PH	0.6516**	1.0000							
LDC	0.6278**	0.4964**	1.0000						
POD	0.6830***	0.7188***	0.6541**	1.0000					
MY	0.6877***	0.6456**	0.4216*	0.5524**	1.0000				
UMY	-0.6853***	-0.6406**	-0.4565*	-0.6127**	-0.7553***	1.0000			
TY	0.6538**	0.6143**	0.3945*	0.5142**	0.9933***	-0.6746***	1.0000		
INC	-0.7332***	-0.7421***	-0.4626*	-0.5125**	-0.7283***	0.5941***	-0.7157***	1.0000	
APH	-0.7416***	-0.7757***	-0.5721**	-0.5986**	-0.7686***	0.7738***	-0.7294***	0.8365***	1.0000

*Where, *=p<0.05, **=p<0.01 and ***=p<0.001*

***BN**= branch number; **PH** =plant height; **LDC**=leaf canopy cover; **POD**= pod number; **MY** =marketable yield; **UMY** =unmarketable yield; **TY**=total yield; **INC**= viral incidence; **APH**= aphids population per plant.*

5. CONCLUSION AND RECOMMENDATION

Pepper is an important cash and spice crop in Ethiopia. It is widely cultivated in some part of Ethiopia especially in the rift valley. However, the production is affected by abiotic and biotic factors. Among biotic factors, viral disease transmitted by vectors is one of the main problem productions of pepper in the central rift valley of Ethiopia.

In Ethiopia, there is a gap in managing viral diseases of crop plants (including pepper) in a way that increases the quantitative and qualitative yield of peppers. Hence, the present study aims to contribute towards effective and sustainable management of pepper virus for improved yields. The field survey was conducted in three major pepper growing districts; namely Butajira, Meki and Ziway rifty valley of Ethiopia. Survey results revealed the wide distribution of viral disease and its vectors in the study area. As a result there appears to be urgent need in considering management options against pepper viruses if pepper production is to be sustained in the region. Pepper viruses and vectors were more distributed in Butajira district, where more cultivated crops species and other hosts were available during survey times, than in Meki and Ziway.

The field experiment determined the role of netting cover in protecting pepper plants from pepper viruses and their vectors. Over all, significant increase in virus infection and aphids infestation was recorded at both experimental fields (Hawassa and Meki), when pepper plants grew without netting. This was followed by significant reduction in growth parameters (plant height, number of branches per plant and leaf canopy cover) and yield, especially marketable yield. The effect was comparable to weekly spraying with insecticide, suggesting the inefficiency of the applied insecticide. On the other hand, net cover up to 80 days or more significantly reduced pepper viruses and their vectors while significantly improving yield and yield component.

However, results of the current experiments are based on only two locations and survey is based on only three districts. Therefore, more experiments should be conducted across different agro ecological zones in different seasons. Finally, researches for more viral diseases and vectors control options should continue to come up with effective, sustainable and affordable disease and insect vectors management strategies.

6. REFERENCES

Acquaah G. 2004. Horticulture: Principles and Practices, 2nd (Ed). Prentice Hall of India Private Ltd. New Delhi, India, 787p.

Agranovsky A.A. 1993. Virus diseases of pepper (*Capsicum annuum L*) in Ethiopia. *Phytopathology*, 138:89-97.

Agrios G.N. 2005. Department of Plant Pathology, 5th (Ed). Academic Press Inc. University of Florida, 703p.

Agrios G.N. and Walker M.E. 2005. Effect of *Cucumber mosaic virus* inoculation at successive weekly intervals on growth and yield of pepper (*Capsicum annuum*) plants. *Journal of Plant Disease*, 69:52-55.

Alegbejo M.D. 1986. Aphid transmission of Pepper veinal mottle virus. *Samaru Journal of Agricultural Research*, 4:71-77.

Alemayehu N., Hoekstra D., Berhe K. and Jaleta M. 2010. Irrigated vegetable promotion and expansion: The case of Ada'a District, Oromia Region, Ethiopia. Improving the productivity and market success of Ethiopian Farmers (IPMS) Case Study Report, International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia.

Alicon J.B. 1984. Haustec Mayan Ethno botany. In: Bosland, P.W. and Votava E.J. (eds). Peppers: Vegetables and Spice Capsicums. CABI publishing, New York, 1-10p.

Aliyu L., Ahmed M.K. and Ado S.G. 2002. Relationship between some characters in Chilli pepper (*Capsicum frutescens*). *Newsletter*, 10: 47-48.

Atiri G.I., and Dele H.W. 1985. Pepper veinal mottle virus infection, host reaction, yield and aphid transmission in pepper plants. *Journal of Tropical Agriculture*, 62:190-192.

Atsebeha S., Alemu T. and Azerefegne F. 2009. Diversity of aphids in the central rift valley of Ethiopia and their potential as vectors for Ethiopian Pepper Mottle Virus (EPMV). *Journal of Entomology and Nematology*, 1:1-6.

Avilla C., Collar J.L., Duque M. and Fereres A. 1997. Yield of bell pepper (*Capsicum annuum*) inoculated with CMV and/or PVY at different time intervals. *Journal of Plant Disease Protection*, 104:1-8.

Berhanu Yadeta, Derbew Belew, Wosene Gebresillassie and Fekadu Marame. 2011. Variability, heritability and genetic advance in hot pepper (*Capsicum annuum* L.) genotypes in west Showa, Ethiopia. *American Eurasian Journal of Agriculture and Environmental Science*, 10(4): 587 –592.

Beyene T. and David P. 2007. Ensuring Small Scale Producers in Ethiopia to Achieve Sustainable and Fair Access to Pepper Market. *Uganda Journal of Agriculture*, 3(2): 113-119.

Black L.L., Green S.K., Hartman G. L. and Poulos J.M. 1991. Pepper diseases: A field guide. Asian Vegetable Research and Development Centre, AVRDC Publication No. 91-347; Shanhua, Taiwan, 98p.

Bos L. 1999. Plant viruses, Unique and Intriguing Pathogens. Backhuys Publishers, 368p.

Bosland P.W. and Votava E.J. 2000. Peppers: Vegetables and Spice *Capsicums*. Crop production science in horticulture, series No 12. CBI Publishing. UK, 96-98p.

Broadbent L. 1969. Disease control through vector control, 593-630p. In: K. Maramorosch. (Ed.). Viruses, Vectors and Vegetation. Interscience Publishers, John Wiley and Sons, Inc.

Brunt A., Crabtree K., Dallwitz M., Gibbs A. and Watson L. 1996. Viruses of Plants: Descriptions and Lists from the VIDE Database. CAB. International, UK, 1484p.

Brunt A.A. and Kenten R.H. 1971. Pepper veinal mottle virus a new member of the *potato virus* Y group from peppers (*Capsicum annuum* L. and *C. frutescens* L.) in Ghana. *Annals of Applied Biology*, 69:235-243.

Central statistical agency (CSA). 2016/2017. Agricultural sample survey volume I report on area and production of major crops (private peasant holdings, meher season). *Statistical bulletin.* 584, Addis Ababa, Ethiopia.

Damiri N. 2014. Mixed viral infection and growth stage on chilli (*Capsicum annuum* L.) production. Pertanika. *Journal of Tropical Agriculture Science*, 37(2):275–283.

Delelegn S. 2009. Evaluation of elite hot pepper varieties (*capsicum species*) for growth, dry pod yield and quality under Jimma condition, south west Ethiopia. M.Sc. thesis, Jimma University, Jimma, Ethiopia.

Dennis S.A. 2013. Learn How to Grow Peppers. Nairobi, Kenya, 1-4p

DeWijs J.J., Strum E. and Schwinn F.J. 1979. The viscosity of mineral oils in relation to their ability to inhibit the transmission of stylet-borne viruses. *Netherlands Journal of Plant Patholology*, 85:19-22.

Diez M.J., Rosello S., Nuez F., Costa J., Lacasa A. and Catala M.S. 1999. Tomato production under mesh reduces crop loss to Tomato spotted wilt virus in some cultivars. *Horticultural Science*, 34:634–637.

DiFonzo C.D., Ragsdale D.W., Radcliffe E B., Gumestad N.C. and Secor G.A. 1997. Seasonal abundance of aphid vectors of *Potato virus* Y in the Red River Valley of Minnesota and North Dakota. *Journal of Economic Entomology*, 90: 824-831.

Dorland R.E. 1974. Plant growth and controlled condition VI Growth and fruiting of the chilli (*Capsium annuam*.L.). *American Journal of Botany*, 34:393-401.

Douglas H. 2008. Facilitating poor market chain innovation: An assessment of the participatory market chain approach in Uganda. International Potato Centre (CIP), Lima, Peru. Working Paper No. 1: 46p.

Eastop V.F.1977. Worldwide importance of aphids as virus vectors. In: Harris K F. and Maramorosch K. (Eds.). Aphids as Virus Vectors. Academic Press, Inc. 4-61p.

Eckel R.V. and Lampert E.P. 1993. Spatial and temporal analysis of tobacco etch virus distribution and its relationship to aphid (Homoptera: Aphididae) vectors in flue-cured tobacco. *Journal of Economic Entomology*, 86:1534-1545.

Edwardson J.R. 1997. Viruses infecting solanaceous crops, University of Florida Extension Station, IFAS.

Esayas Kinfe. 2009. Nutritional composition, physicochemical and functional properties of some capsicum varieties grown in Ethiopia. Master of Science in Food Science and Nutrition. Addis Ababa University, Ethiopia.

Espinoza H.R. and McLeod P.J. 1994. Use of row cover in cantaloupe (*Cucumis melo* L.) to delay infection of aphid-transmitted viruses in Honduras. *Turrialba*, 44:179-183.

Ethiopian Agricultural research Organization (EARO). 2004. Released crop varieties and their recommended cultural practices. Progress report. Addis Ababa, Ethiopia.

Ethiopian Export Promotion Agency (EEPA). 2003. Spice Potential and Market Study. Product Development and Market Research Directorate, Addis Ababa.

Ethiopian Horticulture Development Agency (EHDA) 2011/2012. Exporting Fruit and Vegetables from Ethiopia: Assessment of development potentials and investment options.

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

Fajinmi A.A. 2011. Agro-ecological incidence and severity of *Pepper veinal mottle* virus, genus Potyvirus, family Potyviridae, on cultivated pepper (*Capsicum annuum* L.) in Nigeria. *Arch Phytopathology Plant Protection,* 44(4):307–319.

Fajinmi A.A. and Fajinmi O.B. 2010. Incidence of *okra mosaic virus* at different growth stages of Okra plants (*Abelmoschus esculentus* L. (*Moench)*) under tropical condition. *Journal of General and Molecular Virology*, 2: 028-031.

Fajinmi A.A. and Odebode C.A. 2010. Evaluation of maize/pepper intercropping model in the management of *Pepper veinal mottle virus*, genus Potyvirus, family Potyviridae on cultivated pepper (Capsicum annuum L.) in Nigeria. *Arch Phytopathology Plant Protection*, 43(15):1524–1533.

Farias L.J., Orozco S.M. and Perez J. 1999. Effect of plastic mulch, floating row cover and micro tunnels on insect populations and yield of muskmelon. *Plasticulture*, 118:6-13.

Fekadu Marame and Dandena Galmesa. 2006. Status of Vegetable Crops in Ethiopia. *Ugandan Journal of Agriculture*, 12(2): 26-30.

Francki R.I.B., Mossop D.W. and Hatta T. 1979. Cucumber mosaic virus. CMI/AAB. Description of Plant Viruses No. 213.

Fuchs T.W. and Minzenmayer R. 1999. Effects of Aphis gossypii on cotton development and yield in west Texas. *Southwestern Entomologist*, 20: 341-349.

Funderburk J. 2009. Management of the western flower thrips (Thysanoptera: Thripidae) in fruiting vegetables. *Florida Entomologist*, 92:1–6.

Gowda K.T.P. and Reddy H.R. 1989. Aphid-transmitted viruses infecting chilli. *Current Research-University of agricultural Sciences*, 18(5):71-72.

Green S.K. and Kim J.S. 1991. Characteristics and control of virus infecting pepper: A literature review. *Technical Bulletin*. 18, AVRDC, Taiwan.

Gunasinghe U.B., Irwin M.E. and Kampmeier G.E. 1988. Soybean leaf pubescence affects aphid vector transmission and field spread of soybean mosaic virus. *Annual Applied of Biology*, 112:259–272.

Heinrichs E.A., Aequino G.B. and Palis F. 1986. Integration of host plant resistance and insecticides in the control of *Nephotettix virescence* (Homoptera: Cicadellidae), a vector of rice tungro virus. *Journal of Economic Entomology*, 79:437–443.

Herms, D. A. and Mattson, W. J. 1992. The dilemma of plants to grow or defend. *Quarterly Rev. Biology*, 67:283-335.

Hooks C.R. and Fereres A. 2006. Protecting crops from non-persistently aphid-transmitted viruses: a review on the use of barrier plants as a management tool. *Journal Virus Resistance*, 120:1–16.

Irwin M.E. and Ruesink W.G. 1986. Vector intensity: A product of propensity and activity, 13-33p. In: McLean G.D., Garret R.G. and Ruensink W.G. (Eds.). Plant Virus Epidemics: monitoring, modeling and outbreaks. Sydney, Academic Press.

Jones A.T. 1993. Experimental transmission of viruses in diagnosis. In: Diagnosis of Plant Virus Diseases, 49-72p. (Matthews R.E.F., ed). CRC Press, Florida, USA.

Kapooria R.G. 1999. Identification and incidence of virus diseases of Capsicum annuum in the Lusaka Province of Zambia. *EPPO Bulletin*, 29:183–189.

Kefayalew A. 2008. Characterization and classification of irrigated soils and irrigation waters of major water supply sources in Meki-Ogolcha area. MSc Thesis, Haramaya University, Ethiopia.

Kooner B.S. and Cheema H.K. 2007. Screening of Mungbean germplasm against whitefly (Bemisia tabaci Genn.) and Mungbean yellow mosaic virus. *Acta Horticultural*, 752:307–309.

Liu B., Gumpertz M.L., Hu S. and Ristaino J. 2008. Effect of prior tillage and fertility amendments on dispersal of *Phytophthora capsici* and infection of pepper. *Euretical Journal of Plant Pathology,* 120:273-287.

Loebenstein G., Berger P.H., Brunt A.A. and Lawson R.H. 2001. Virus and virus-like diseases of potatoes and production of seed potatoes. Kluwer Academic Publisher, Dortrecht.

Makkouk K.M. and Gumpf D.J. 1974. Characterization of potato virus Y strains isolated from pepper. *Phytopathology*, 66:576-581.

Marame F., Fininsa C., Singh H., Dessalegne L., Andersson A. and Sigvald R. 2010. Occurrence of aphid vector and genetic tolerance to infection by potyvirus in hot pepper. *Euphytica*, 172: 85-91.

Mazourek M., Pujar A., Borovsky Y., Paran I., Mueller L. and Jahn M.M. 2009. A dynamic interface for capsaicinoids systems biology. *Plant Physiology*, 150:1800-1881.

Melkasa Agricultural Research Center (MARC). 2004. Progress Report on Completed Activities, 1-7p.

Meyers L., Martin R. and McDonald S. 1998. The effect of *tobacco etch virus* on the growth and yield of two pepper *Capsicum chinense* varieties. In: Proceedings of the joint JSAS/ 34th Annual conference of the CFCS, Montego Bay, Jamaica, July 12-18.

Mills P.R. and Abdul-Magid M. 1987. Infection of *Capsicum frutescens* with potato virus Y and tobacco etch virus in the Sudan. *Plant Disease*, 71:557.

Moyer A. 1999. *Tospoviruses* (Bunyaviridea). In: A. Grannof and R.G. Webster (eds) Encyclopedia of Virology 2nd (Ed), 1803- 1807p.

Mukasa S.B., Rubaihayo P.R., and Valkonen J.P. 2003. Incidence of viruses and virus like diseases of sweet potato in Uganda. *Plant Disease*, 87:329-335.

Muller H.J. 1959. The relations between aphid vectors and viral transmission. *Journal of Entomology*, 3: 229-258.

Mushtaq S., Shamim F., Shafique M. and Haider M.S. 2014. Effect of whitefly transmitted Giminiviruses on the physiology of tomato *(Lycopersicon esculentus* L) and tobacco *(Nicotiana benthamiana* L) plants. *J. Nat. Sci. Res*, 4(9):109-119.

Myers L.R.S. 1996. The etiology of viruses affecting pepper (*Capsicum* spp.) in Jamaica. Masters Thesis, University of the West Indies, 142p.

Nault B.A., Saha D.A., Dillard H.R. and Mcfaul A.C. 2004. Seasonal and spatial dynamics of alate aphid dispersal in Snap bean in proximity to alfalfa and implication for virus management. *Environmental Entomology*, 33(6):1593-1601.

Nault L.R. 1997. Arthropod transmission of plant viruses: a new synthesis. *Annals of the Entomological Society of America*, 90:521-541.

Nelson M.R. and Wheeler R.E. 1978. Biological and serological characterization and separation of potyviruses that infect peppers. *Phytopathology*, 68:979-984.

Ochoa-Alejo N. and Ramirez-Malagon R. 2001. *In vitro* chilli pepper biotechnology. *In Vitro Cellular and Developmental Biology Plant*, 37:701-729

Olobashola N., Salaudeen M.T. and Achikwu M. 2017. Growth and yield Responses of Sweet Pepper (Capsicum Annuum L.) Cultivars to Infections with *Cucumber mosaic virus* Disease. *Nigerian Journal of Agriculture, Food and Environmental,* 13(1):201-205.

Ong C.A., Arghese G. and Poh T.W. 1984. The effect of Chili veinal mottle virus on yield of chili (Capsicum annuum L.). Malaysia Agriculture Research and Development Institute. *Research Bulletin*, 8: 74-79.

Ou B., Huang D., Hampsch-Woodill M., Flanagan J.A. and Deemer E.K. 2002. Analysis of antioxidant activities of common vegetables employing oxygen radical absorbance capacity (ORAC) and ferric reducing antioxidant power (FRAP) assays: a comparative study. *Journal of Agricultural and Food Chemistry*, 50: 3122-3128.

Pappu H.R., Csinos A.S., McPherson R.M., Jones D.C. and Stephenson M.G. 2000. Effect of acibenzolar S-methyl and imidacloprid on suppression of tomato spotted wilt tospovirus in flue-cured tobacco. *Crop Protection*, 19:349–354.

Parvatha Reddy P. 2009. Advances in integrated pest and disease management in horticultural crops, volume 1: vegetable crops. Studium Press (India) Pvt ltd., New Delhi.

Pazarlar S., Gumus M. and Oztekin G.B. 2013. The Effects of *Tobacco mosaic virus* Infection on Growth and Physiological Parameters in Some Pepper Varieties (*Capsicum annuum* L.). *Notulae Botanicae Horticultural Agrobotanical-Napoca*, 41(2):427-43.

Pirone T.P., Raccah B. and Madden L.V. 1988. Suppression of aphid colonization by insecticides: effect on the incidence of potyvirus in tobacco. *Plant Disease*, 72:350–353.

Purcifull D.E. and Hiebert F. 1982. Tobacco etch virus. CMI/AAB Descriptions of Plant Viruses No. 258. Common Wealth Mycological Institute, Kew, England. 4p.

Purcifull D.E., Zitter T.A. and Hiebert E. 1975. Morphology, host range, and serological relationships of pepper mottle virus. *Phytopathology*, 65: 559-562.

Purseglove J.W., Brown E.G., Green C.I. and Robbins S.R.I. 1981. Spices. Vol.1. Longman Inc. New York. 365p.

Raccah B. 1983. Monitoring insect populations and the detection of viruses in vectors, 147p. In: R.T. Plumb and J.M. Thresh. (Eds.). Plant Virus Epidemiology.

Raccah B., Gal-On A. and Eastop V.F. 1985. The role of flying aphid vectors in the transmission of cucumber mosaic virus and potato virus Y to peppers in Israel. *Annals of Applied Biology*, 106:451-460.

Rahman M.J., Uddin M.S., Bagum S.A., Mondol A.T. and Zaman M.M. 2006. Effects of mulches on the growth and yield of tomato in the coastal area of Bangladesh under rain-fed condition. *International Journal of Sustainable Crop Production*, 1: 06 -10.

Rao G.P., Chateret M., Gigard J.G. and Rott P. 2006. Distribution of Sugarcane mosaic and Sugarcane streaked mosaic virus in India. *Sugar Technology*, 8:79–81.

Rao R.G.S. and Mathura R. 2004. Seed quality enhancement by gravity separation in solanaceous vegetables. Division of Crop Improvement, Indian Institute of V getable Research, India. *Annals of Agricultural Bioresearch*, 9(2): 145-149.

Rubatzky V.E. and Yamaguchi M.M. 1997. World vegetables: principles, production and nutritive values, 2nd ed., Chapman and Hall International Thomson Publishing, New York. 843p.

Russo V.M. and Biles C.L. 2004. Fertilizer rate and galactosidase and peroxidase activity in pepper fruit at different stages and years of harvest. *Plant Foods, Human Nutrition*, 58:231-239.

Sastry K.S. 2014. Plant Virus and Viroid Diseases in the Tropics.

Sharma O.P., Sharma P.P. and Chowfla S.C. 1989. Inheritance of resistance to potato virus Y in garden pepper (*Capsicum annuum* L). *Euphytica*, 42(1-2):31-33.

Shepherd R.J. 1977. Intrinsic properties and taxonomy of aphid-borne viruses, 121-136p. In: K.F. Harris and K. Maramorosch. (Eds.). Aphids as Virus Vectors. Academic Press Inc.

Shirshikar S.P. 2008. Integrated management of sunflower necrosis disease. HELIA, 31:27–34.

Shukla D.D., Ward C.W. and Brunt A.A. 1994. The Potyviridae. Cambridge, UK: CABI International.

Simons J.N. 1982. Use of oil sprays and reflective surfaces for control of insect-transmitted plant viruses, 71-93p. In: K.F. Harris and K. Maramorosch. (Eds.). Pathogens, Vectors and Plant Viruses. Academic Press.

Simons J.N. and Beasley C.A. 1977. Visualization of oil on leaf surfaces technique. *Journal of Economic Entomology*, 70:307-308.

Simons J.N., Simons J.E. and Simons J.L. 1995. JMS Stylet-Oil User Guide: as a fungicide, as an insecticide and for plant virus control. Version 2.1. JMS Flower Farms Inc. 41p.

Statistical Analysis System (SAS). 2002. SAS for windows released 9.0. SAS institute, Inc. Cary, NC, USA.

Summers C.G. and Stapleton J.J. 2002. Use of UV reflective mulch to delay the colonization and reduce the severity of *Bemisia argentifolii* (Homoptera: Aleyrodidae) infestations in cucurbits. *Crop Protection*, 21:921–928.

Summers C.G., Mitchell J.P. and Stapleton J.J. 2004. Management of aphid borne viruses and Bemisia argentifolii (Homoptera: Aleyrodidae) in zucchini squash by using UV reflective plastic and wheat straw mulches. *Environmental Entomology*, 33:1447–1457.

Sun X., Nielsen M.C. and Miller J.W. 2002. Bacterial Spot of Tomato and Pepper. Plant Pathology Circular No. 129 (Revised) April/ May; Fl. Dept. Agriculture and Cons. Svcs. Division of Plant Industry.

Sylvester E.S. 1969. Virus transmission by aphids a viewpoint, 159-173p. In: K. Maramorosch (ed). Viruses, Vectors, and Vegetation. Interscience Publishers, John Wiley &Sons, Inc.

Sylvester E.S. 1980. Circulative and Propagative virus transmission by aphids. *Annual Review of Entomology*, 25: 257-286.

Taiz L. and Zeiger E. 2010. Plant physiology. Sinauer Associates Inc, Sunderland, Massachussetts, USA

Tameru A. 2004. Characterization of virus of pepper (*Capsicum* spp.) and sweet potato (*Ipomoea batatas*) from Ethiopia. PhD Thesis, University of Bonn, Germany. 150p.

Tameru A., Hamacher J. and Dehne H.W. 2003. The increase in importance of Ethiopian pepper mottle Virus (EPMV) in the rift valley parts of Ethiopia: Time to create awareness among researchers and extension workers. Paper presented at Deutsches, Tropentage, October 18-21, 2003, Gottingen, Germany.

Thakur P.C. 1993. Heritability in sweet pepper: Capsicum Newsletter. Institute of plant breeding and seed production. Giuria Turin, Italy, 7: 42- 43.

Thakur P.D., Chowfia S.C. and Khurana S.M. 1988. Natural occurrence of an atypical strain of potato virus Y on bell pepper in Himachal Pradesh. *Indian Journal of Virology*, 4(1-2): 91-96.

Thresh J.M. 2006. Control of tropical plant virus diseases. *Advanced Virus Resistance*, 67:245–295.

Tindall J.A., Beverly R.B. and Radcliffe D.E. 1990. Mulch effect on soil properties and tomato growth using micro-irrigation. *Journal of Agronomy*, 83:1028-1034.

Tomlinson J.A. 1987. Epidemiology and control of virus diseases of vegetables. *Annals of Applied Biology*, 110: 661-681.

Tsedeke A. 1988. Insect and mites pests of horticultural and miscellaneous plants in Ethiopia. Ethiopian Institute of Agriculture Research Handbook, 1:20-25.

Tusiime G., Tukamuhabwa P., Kalubo S., Awori E. and Tumwekwase S. 2010. Development of a hot pepper root rot and wilt disease management strategy through genetic resistance, chemical application and proper choice of rotational crops. Second Ruforum Biennial, Meeting 20-24, September 2010, Entebbe, Uganda.

Villalon B. 1981. Breeding peppers to resist virus diseases. *Plant Disease*, 65:557-562.

Wang R.Y. and Pirone T.P. 1996. Mineral oil interferes with retention of tobacco etch potyvirus in the stylets of Myzus persicae. *Phytopathology*, 86:820-823.

Yaynu H. 2001. Characteristics of isolates of *Pseudomonas solanacearum* in Ethiopia. *Ethiopian Journal of Agricultural Science*, 11:7-13.

Yaynu H., Lesemann D. and Vetten H.J. 1999. Occurrence, distribution and relative importance of viruses infecting hot pepper and tomato in the major growing areas of Ethiopia. *Phytopathology*, 147: 5-11.

Yosef H. and Yayeh. Z. 1989. Hot pepper and tomato production in Ethiopia, In: Green S K., Griggs T.D and McLean B.T (eds). Tomato and pepper production in the tropics proceedings of the international symposium on integrated management practices. AVRDC 21-26, March 1988, Tainan, Taiwan. 442-451p.

Zitter T.A. 1975. Transmission of pepper mottle virus from susceptible and resistant pepper cultivars. *Phytopathology*, 65:110-114.

Zitter T.A., Florini D. and Providenti R. 1984. Virus diseases of pepper. Vegetable Crops Fact Sheet, 730p. Cornell University, USA.

7. APPENDICES

Appendix Table 1: Mean square values of average disease incidence, final disease incidence and aphids population per plants as influenced by netting duration at Hawassa location

Source of variation	df	Average disease incidence	Final disease incidence	Aphid population per plant
Netting duration	6	675.6366**	1367.5833**	467.1875**
Error	21	63.3961	36.9404	21.1688

NB: and ** indicates significance at 5% and 1% probability levels, respectively; df=degree of freedom*

Appendix Table 2: Mean square values of average disease incidence, final disease incidence and aphids population per plants as influenced by netting duration at Meki location

Source of variation	df	Average disease incidence	Final disease incidence	Aphid population per plant
Netting duration	6	470.1636**	1235.1190**	545.7042**
Error	21	13.2440	29.7619	60.5373

*NB: *and ** indicates significance at 5% and 1% probability levels, respectively; df=degree of freedom*

Appendix Table 3: Mean square values of number of branches per plant, plant height per plant, leaf canopy cover per plant and number of pods per plant as influenced by nets at Hawassa location

Source of variation	df	Number of branches per plant	Plant height per plant	Leaf canopy cover per plant	Number of pods per plant
Netting duration	6	20.2901**	486.7603**	51.4214*	50.4761**
Error	21	2.6422	10.4142	15.3542	6.0678

*NB: * and ** indicates significance at 5% and 1% probability levels, respectively; df=degree of freedom*

Appendix Table 4: Mean square values of number of branches per plant, plant height per plant, leaf canopy cover per plant and number of pod per plant as influenced by netting duration at Meki location

Source of variation	df	Number of branches per plant	Plant height per	Leaf canopy cover per plant	Number of pods per plant
Netting duration	6	4.7723ns	52.6260**	38.6611**	9.3123**
Error	21	1.5580	4.3586	3.1415	1.1975

NB: and ** indicates significance at 5% and 1% probability levels, respectively; ns =non-significant; df=degree of freedom*

Appendix Table 5: Mean square values of marketable yield, unmarketable yield and total yield as influenced by netting duration at Hawassa location.

Source of variation	df	Marketable yield	Unmarketable yield	Total yield
Netting duration	6	30.5367**	0.7677**	21.7217**
Error	21	3.6613	0.0842	3.5540

*NB: * and ** indicates significance at 5% and 1% probability levels, respectively; df=degree of freedom*

Appendix Table 6: Mean square values of marketable yield, unmarketable yield and total yield as influenced by netting duration at Meki location

Source of variation	df	Marketable yield	Unmarketable yield	Total yield
Netting duration	6	18.3599**	1.0544**	10.9782**
Error	21	2.5766	0.1546	2.4149

NB: and ** indicates significance at 5% and 1% probability levels, respectively; df=degree of freedom*

BIOGRAPHY

The author was born in 1994 at Kuyu Woreda, in the North Shewa Zone of Oromiya Regional State, Ethiopia. He attended elementary school grade (1-8) at Kesi Elementary School. After completing Elementary, he joined Gerba Gurracha Secondary and Preparatory School to pursue 9^{th}-12^{th} grades.

Then he joined Ambo University in 2013 and graduated with the degree of Bachelor of Science in plant science in June 2015. Immediately following graduation, he was assigned by the minister of education in October 2015 to Hawassa University to pursue a study leading to the degree of Master of Science in crop protection.