Plant Protection, 04 (03) 2020. 137-147 DOI: 10.33804/pp.004.03.3350

Available Online at EScience Press
Plant Protection
ISSN: 2617-1287 (Online), 2617-1279 (Print)
http://esciencepress.net/journals/PP

A BRIEF DESCRIPTION OF TOMATO LEAF CURL VIRUS AND ITS MANAGEMENT

Mustansar Mubeen[1], Yasir Iftikhar[2], Qaiser Shakeel[3], Farazia Hassan[4], Aqleem Abbas[1], Usama Ahmad[5], Muhammad Shahid[6]

[1] State Key Laboratory of Agricultural Microbiology and Provincial Key Laboratory of Plant Pathology of Hubei Province, College of Plant Science and Technology, Huazhong Agricultural University, Wuhan 430070, Hubei, P.R. China.
[2] Department of Plant Pathology, College of Agriculture, University of Sargodha, Sargodha 40100, Pakistan.
[3] Department of Plant Pathology, University College of Agriculture and Environmental Sciences, The Islamia University of Bahawalpur, Bahawalpur, Pakistan.
[4] Department of Bioinformatics, Faculty of Science and Technology, Virtual University of Pakistan, Samundri Campus, Pakistan.
[5] Department of Horticulture, Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan.
[6] Plant Pathology Research Institute, Ayyub Agricultural Research Institute, Faisalabad, Pakistan.

ARTICLE INFO

Article history
Received: 13th September, 2020
Revised: 7th November, 2020
Accepted: 27th December, 2020

Keywords
Tomato
Tomato Leaf Curl Virus
Etiology
Physiology
Management

ABSTRACT

The tomato crop is affected by various biotic and abiotic factors. Among the biotic factors, Tomato Leaf Curl Virus (TLCV) is one of the most devastating viruses of tomato. The virus belongs to *Begomovirus* and family *Gemniniviridae.* The genome of virus is single-stranded-DNA. It is naturally transmitted through whitefly (*Bemisia tabaci*). The virus is responsible for causing severe economic losses up to 80% in tomato crop-growing regions and continuously threatening the tomato crops. The increasing severity of TLCV has compelled plant virologists to develop accurate detection and identification of the virus. TLCV is responsible for certain biochemical changes and considerably affecting the plant growth. Tomato Leaf Curl Virus is significantly influenced physiological parameters and metabolic activities of all tomato varieties. The biochemical changes of cellular components are caused due to morphological deviation of infected virus plants, and symptoms expressed by the plants can determine the magnitude of the vegetable losses. It is evident from the previous reports, that nutrients were effective in reducing TLCV from a tomato plant. Moreover, the usage of resistant varieties and controlling of whitefly population and management of TLCV by different nutrients are some of the economical and recommendable ways to manage TLCV. Among the organic management strategies, the compost is also considered best in suppressing disease severity. Moreover, epidemiology plays a vital role in the spread and progress of the disease. Keeping in view the importance of TLCV and its effects on tomato crop, the present review will highlight the etiology, physiology and management of TLCV.

Corresponding Author: Mustansar Mubeen
Email: mustansar01@yahoo.com

INTRODUCTION

Vegetables are playing a major role in the human diet and are abundantly used in everyday life. Among the vegetables, tomato (*Solanum lycopersicum*) is one of the most valuable vegetable crops found all over the world. Tomatoes are short duration and winter season perennial crop being cultivated everywhere in the world. Tomatoes were initially recorded from Mexico. Tomatoes were originated from South America and contained more than 3000 species of the plants. Mineral composition in tomatoes is dependent upon quantity and sort of mineral occupied from growth media and soil. Insufficient quantities of nutrients accessibility illustrate deficiency symptoms and affect the production and quality of tomato (Sainju et al., 1999). Sugars, dietary fibers, carotenoids and antioxidant pigment named lycopene gives the red colour to tomatoes are present, which aids in the suppression of carcinogenic substances and considered beneficial for the health of human beings (Arooj et al., 2017). Colour is very important to judge the quality of fruit, and the red colour of tomato is because of the production of an antioxidant compound named lycopene and the degradation of chlorophyll pigments. Antioxidant activity and the total number of carotenes in tomatoes are dependent on age and variety (Arias et al., 2000). Among the top ten tomato producing countries of the world, China ranked top followed by USA (Arooj et al., 2019). Pakistan's climatic conditions vary from tropical to a temperate climate, and these conditions favour the growth of different types of 40 vegetables and 21 fruits (Raja and Khokhar, 1993). Tomato constitutes an area of 4.41 million hectares in the world and 151.69 million tons are produced annually (Arooj et al., 2019). Tomato crop is subjected to various biotic and abiotic factors affecting the crop. Growth of plant and crop yield are also adversely affected by various abiotic stresses (Hasegawa et al., 2000). Among the biotic factors, pathogens like fungi, bacteria, viruses, mollicutes and nematodes are a serious threat and causing considerable yield losses in tomato fields. Every year there are huge crop losses due to these pathogens. Among these biotic factors, plant viruses exhibit local or systemic infections as they can diverge the physiology of plant from its typical behaviors (Arooj et al., 2019). Plants infected with virus characteristically show stunted, crinkled and bear small fruits or no fruits. In few cases, infected plants exhibit dieback symptoms before flowering occurs (Hanssen et al., 2010). Seven different viral diseases have been reported in Pakistan namely Tomato leaf curl virus (TLCV), Tomato mosaic virus (ToMV), Potato virus X (PVX), Cucumber mosaic virus (CMV), Tomato yellow top virus (TYTV), Tomato spotted wilt virus (TSWV) and Tomato ringspot virus (TRSV) (Mughal, 1985). More than 20 viruses in the world are involved in infecting tomato crop, and losses up to 20-90% were projected by different viruses (Arooj et al., 2019). Among these viruses, TLCV is the foremost limiting factor in the production of tomato and cause 30-40% yield losses in Pakistan (Tariq, 1999). TLCV is among the most devastating virus that is responsible for causing heavy yield losses in tomato crop. TLCV infect tomatoes both in fields and greenhouses. Tomato Leaf Curl and Tomato Yellow Leaf Curl (TYLCV) viruses are responsible for causing considerable yield losses in tomato fields in many tropical, warm temperate regions and sub-tropical regions of the world (Green and Kali, 1994). The virus belongs to the genus *Begomovirus* and family *Gemniniviridae.* It comprises of single-stranded-DNA (Gottlieb et al., 2010; Hanssen et al., 2010). *Geminiviridae* is regarded as the largest family of plant viruses which is composed of circular single-stranded DNA. It comprises of isometric twin particle with 18-20×30 nm size. Among, all four genera of *Geminiviridae, Begomovirus* is accounted as the largest genera. In Pakistan in the early1980s tomato plants displaying TLCV-like symptoms were identified. Now symptoms proceeded all over the tomato-growing regions of Sindh and Punjab (Rana et al., 1992). Lapidot (2007) narrated that in tomato plants, symptoms initiated within 2-3 weeks after getting exposed to viruliferous whitefly (*Bemisia tabaci*). The characteristics symptoms shown by this disease includes lamina of leaf turn yellow, upward curling of leaves, distortion of leaves, lessening of internodes, size of new emerging leaves reduces, wrinkle facade, inhibited growth, and dissemination of flowers occurs from plants before initiation of fruiting. Infected plants look as if they are healthy but eventually develop symptoms that lead to a huge economic loss (Melzer et al., 2010). In 1993, a TLCV isolate was found and maintained in tomato that was inoculated by grafting (Harrison et al., 1997). Consequently, the bipartite *geminivirusis* is affiliated with TLCV in Pakistan (Mansoor et al., 1997). Rana et al. (1992) surveyed the tomato fields in Hyderabad district of Sindh in Pakistan. They reported that 68% of tomatoes were infected with different kinds of viruses. Through host reactions, serological tests, double diffusion and physiological methods, they were able to detect TMV, TLCV, TRSV, CMV and TBRV in the fields. Tomato leaf curl viruses are one of the main viruses that infect tomato crop and their incidence and spread depends upon occurrence and population dynamics of the whitefly (Moriones and Navas-Castillo, 2000) along with weather situations in the agro-ecosystem. Whitefly is regarded as an insect vector responsible for the transmission of TLCV (Sugano et al., 2011). Tomato plant infected with Tomato Yellow Leaf Curl Virus causes certain changes in physiology and structure of plant which results in lessening the growth, photosynthetic pigments, carbohydrate contents, Mg++ ions while sodium level increases which are considered as a defense mechanism when the plant is under stress conditions; osmotic pressure in cells, uptake of water and nutrients in the form of solutes from the soil (Khalil et al., 2014). To reduce these losses, certain practices are followed like applying different chemicals. TLCV can also be controlled by controlling the vectors. Antignus et al. (2001) narrated that another approach practiced in protected culture is Ultraviolet absorbing plastic films; have presented good results. Polston and Lapidot (2007) said that one more approach that is named as rouging is also highly recommended practice and plants exhibiting early symptoms can be detached to decrease the inoculation source inside the fields. Fanigliulo et al. (2009) suggested that using insecticides like cypermethrin (0.01%) or Dimethoate (0.1%) in the form of sprays can be effective in controlling whitefly which is the vector of TLCV which will result in suppressing TLCV. Holguín-Peña et al. (2007) recommended that nowadays, management is done to suppress diseases caused by *Begomoviruses*. Environmental conditions also play a significant role in disease development (Mubeen et al., 2017). Strategies have developed to avoid transmission of the virus by using whitefly and planting the crop in whitefly-free periods and protect the crops by using row covers. At the same time, insecticides should be applied as the last strategy, which is the most widely used. As little work was done in Pakistan on TLCV and inadequate information is available. Therefore, keeping in view, the significance of TLCV and drastic yield losses to tomato crop, the current review will assist researchers in future to predict the impact of TLCV on tomato crop and to develop eco-friendly management practices.

Interaction between Host and Tomato Leaf Curl Virus

As aforementioned, the Tomato Leaf Curl virus is responsible for causing heavy yield losses in tomato crop sown all over the world. TLCV infects tomatoes growing both in fields and greenhouses. Tomato Leaf Curl and Tomato Yellow Leaf Curl Viruses caused considerable yield losses in tomato fields in many tropical, warm temperate regions and sub-tropical regions of the world (Green and Kali, 1994). Due to the quick spread of TLCV in the previous years, the production of tomato in Pakistan lowered. All over the world, there is great emphasis regarding research to recognize, control this harmful pathogen and reduce crop losses. Mughal (1985) listed seven different viral diseases that are reported in Pakistan namely Tomato leaf curl virus (TLCV), Tomato mosaic virus (ToMV), Potato virus X (PVX), Cucumber mosaic virus (CMV), Tomato yellow top virus (TYTV), Tomato spotted wilt virus (TSWV) and Tomato ringspot virus (TRSV). Mansoor et al. (1997) reported that Tomato leaf curl virus (TLCV) as bi-partite *Gemniviruses* in Pakistan. Krause-Sakate et al. (2005) reported Tomato leaf curl New Delhi virus from New Delhi region of India. TLCV is distributed over a large area and infects several other crops. The severity may vary in intensity, from very trivial symptoms to very severe symptoms and even death of plant may occur in some cases. Melzer et al. (2010) narrated that many hosts of TLCV other than tomato have been reported like eggplants, potatoes, peppers, common beans and weeds. Infected plants look as if they are healthy but eventually develop symptoms that lead to huge economic loss. Hassan et al. (1993) studied the epidemiology of plant viruses. They observed that basic and primary source of viral infection in tomatoes should be endorsed to their vectors like whiteflies, aphids and various leafhopper species.

Etiology

TLCVs and TYLCVs have one monopartite genome (Navot et al., 1991) or two bipartite genomes (Padidam et al., 1995). Bertamini et al. (2004) described that the genome comprised of single-stranded-DNA. *Geminiviruses* are considered as significant plant pathogens encompassing circular single-stranded (ss) DNA genomes which ranged in size from 2.5-3.0 kb. Hanley-Bowdoin et al. (1999) narrated that TLCV and TYLCV are complex composed of a single nucleotide (n), have circular single-stranded DNA (ssDNA) genome encapsulated in twin particles. The TLCVs/TYLCVs replicate inside the infected cells by rolling-circle mechanism, dsDNA intermediate replicative form act as a template. Gafni (2003) documented that TYLCV is single-strand circular DNA (ss circular DNA) and encompass *monopartite* or *bipartite* with 18-20×30 nm geminate size. Gronenborn (2007) explained that TLCV contains twin, an isometric particle whose diameter is

20 nm and length is 30 nm. The single segment of the viral genome consists of the single-stranded DNA molecule with a size of 2.8 Kb nucleotides. It contains replication proteins (Rep), the structural protein (CP), and some other proteins like proteins enhancing replication process (REn), and the proteins involved in activating transcription (TrAP), these all are associated with control of replication and expression of genes. McGregor et al. (2009) explained that the genus *Begomovirus* of family *Geminiviridae* is the most important virus family disturbing crops in the world. Hanssen et al. (2010) described that tomato leaf curl virus is a *geminivirus* which belongs to genus *Begomovirus* from family *Geminiviridae. Geminiviridae* is regarded as the largest family of plant viruses which is composed of circular single-stranded DNA. It comprises of isometric twin particle with 18-20×30 nm size. Amongst all four genera of *Geminiviridae, Begomovirus* is accounted as the largest genera.

Symptomology

Czosnek et al. (1988) proved that TLCV exhibit disease symptoms which are similar to those symptoms caused by Tomato Yellow Leaf Curl Virus (TYLCV). (Lapidot, 2007) narrated that in tomato plants symptoms initiated within 2-3 weeks after getting exposed to viruliferous whitefly. Symptoms begin with small yellowing on the margins of a leaflet in apical leaves and leaflets curl upward and cupping at later stages. After 30 days top leaves exhibit curling, cupping and yellowing, whereas plants stop growing, flowers and fruits are abscised. Melzer et al. (2010) indicated that the characteristics symptoms shown by this disease include lamina of leaf turn yellow, upward curling of leaves, distortion of leaves, lessening of internodes, size of new emerging leaves reduces, wrinkle facade inhibited growth, and dissemination of flowers occurs from plants before initiation of fruiting. Sweet potato whitefly (*Bemisia tabaci*) and silver leaf whitefly (Biotype B; *Bemisia argentifolii*) aids in the transmission of TLCV. Whiteflies harboring virus can infect wide-ranging crops and weeds; like eggplants, potatoes, peppers, and common beans. Infected plants look as if they are healthy but eventually develop symptoms that lead to huge economic loss. Saha et al. (2005) described that the distinguishing symptoms exhibited by the infected susceptible plants include leaf curl, shrinking of leaves occur and reduced plant growth. They reported causal agents of this disease are members of genus *Begomovirus*, and whitefly is regarded as vector and aids in transmission. Czosnek and Ghanim (2012) provoked that TLCV can show distinct symptoms in tomato. Still, it can produce infection in the wild as well as cultivated species without showing any symptoms, although in both cases the host will act as a reservoir for the virus. Hence, whiteflies are capable of acquiring and transmitting the virus from infected non-symptomatic plants regardless of TLCV is deficient in inducing disease symptoms. Arooj et al. (2019) explained that the characteristic symptoms shown by TYLCV include curling of leaflet margins upwards, lessening of leaflet area, adolescent leaves turn yellow, stunted growth and flower termination (Figure 1).

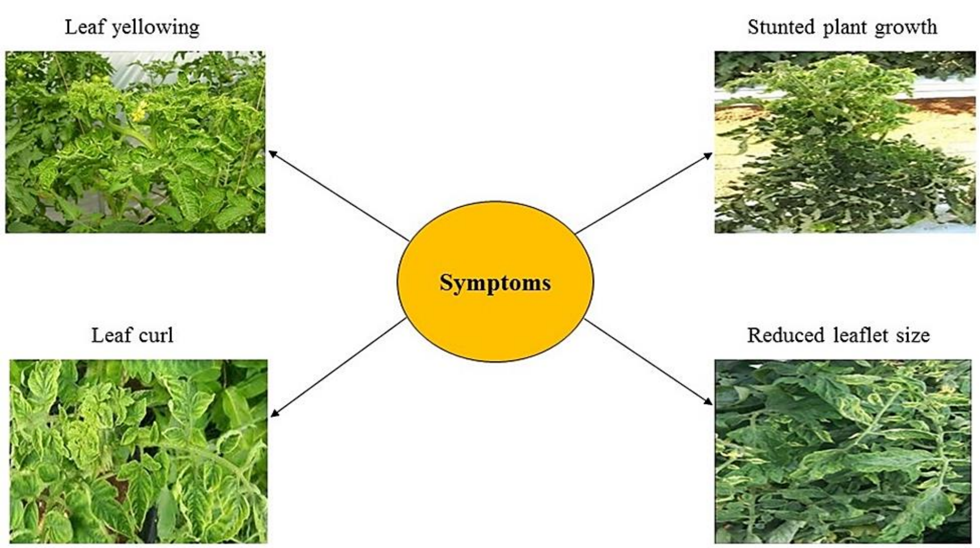

Figure 1. Characteristic symptoms of tomato leaf crinkle virus on tomato crop.

Vector Biology

Insects play a significant role in the virus transmission. Viruses spread from diseased plants to healthy plants with the help of insect vectors. The relationships among plant viruses and insect vectors are much complicated than passive relations (Matthews, 1991). Bedford et al. (1992) described that in Asia (India-Pakistan), esterase banding patterns are used to detect biotypes of whitefly (H and K) other than biotype B; these biotypes were capable of transmitting TYLCV/TLCV. Perring et al. (1993), Bedford et al. (1994) and Brown et al. (1995) reported that the spread of diseases like TYLCV/TLCV and many other *Geminiviruses* that are transmitted by whitefly has often paralleled the expansion of biotype B of *B. tabaci* also called silver leaf whitefly all over the world. Brown et al. (1995) explained that based on a few pieces of evidence, it could be predicted that whitefly might be inherent to somewhat in Pakistan or India. The maximum parasitoid's range was inherent in Indo-Pak subcontinent. Evolutionary association of *B. tabaci* that it might be originated from Tropical Africa and later on migrated towards Southern North America viral acquisition is more efficient as compared to inoculation and females proved to be more efficient than males in transmission. At the same time, nymphs are also very efficient in acquiring the virus, but because of being immobile, they are not epidemiologically important (Cohen and Melamed-Madjar, 1978). Lapidot et al. (2001) said that old tomato fields are supposed to be an important source of TLCV, TYLCV and whiteflies. Whiteflies mostly migrated to young plants from old plants. In those fields where whiteflies are not properly managed virus can quickly spread. Czosnek et al. (2002) explained that whitefly during feeding, take TLCV/TYLCV through the stylet, then passed through the midgut into epithelial cells, and then entered into the hemolymph, where they circulate until they penetrate salivary glands, and finally injected into the plant. Moriones and Navas-Castillo (2000) conducted their trial on tomato and proved that TLCV/TYLCV is the main limiting factor for low yield. Several species and strains of *Begomoviruses* are responsible for inducing disease, amongst them. Sugano et al. (2011) stated that whitefly is regarded as an insect vector responsible for the transmission of TLCV. Sánchez-Campos et al. (2013) reported that Begomovirus belong to *Gemniviruses*, transmitted by whitefly and are responsible for most economic loss. Mostly *Begomoviruses* initiating from the New World have genomes comprising of two constituents, recognized as DNA A and DNA B, both are necessary for viral infection. Shelat et al. (2014) narrated that epidemics of *Tomato leaf curl virus* in the association of expansion of whiteflies in tomato fields have been regularly reported causing yield losses up to 100% in India.

Disease Incidence

Lapidot et al. (2001) reported that in Israel, tomatoes during the summer and autumn seasons were affected by the disease and cause yield loss up to 100% among susceptible cultivars. Tariq (1999) reported that TLCV is the foremost limiting factor in the production of tomato in Pakistan, causing 30-40% yield losses. Saikia and Muniyappa (1989) reported that in Southern part of India, the incidence of TLCVD in susceptible cultivars was above 90%. Hull and Davies (1992) described that plant viral diseases are responsible for heavy losses, particularly in tropics and semi-tropical regions, which served as ideal places for the perpetuation of viruses and different kind of their vectors. Economic losses in tomatoes have also been testified in temperate areas of the world. Moriones and Navas-Castillo (2000) studied that Tomato leaf curl viruses are one of the main viruses that infect tomato crop and their incidence and spread depends upon occurrence and population dynamics of the whitefly. Lapidot et al. (2001) stated that *B. tabaci* transmits TYLCV and causes crop losses to even 100% throughout the summer and autumn seasons. About 21 different types of Tomato leaf curl viruses were so far reported in India. Singh et al. (2014) reported that plant breeders had made innumerable efforts to reduce TLCD through conventional breeding. Currently, no fruitful report has been highlighted regarding the immunity of this virus. Tomato's yield is topmost constrain as numerous abiotic and biotic aspects effect the virus. Tomato leaf curl disease is one of the main aspects which expressively decreased the production of tomato. It is initiated by different strains of Tomato leaf curl virus triggering yield loss of about 100% in several portions of India. Hassan et al. (1993) reported that viral diseases of winter tomato in Malakand agency of NWFP, Pakistan. They calculated the mean of incidence of different viruses ToMV 34.38%, CMV 12.92%, TLCV 15.08%, and Tomato Yellow Top Virus 8.26% based on symptoms. Rana et al. (1992) surveyed the tomato fields in Hyderabad district of Sindh in Pakistan. The 68% tomatoes were reported to be infected with different kinds of viruses. Through host reactions,

 DOI: 10.33804/pp.004.03.3350

serological tests, double diffusion and physiological properties, they were able to detect TMV, TLCV, TRSV, CMV and TBRV in the fields. Khan (1997) surveyed tomato producing areas of Malakand Agency and Peshawar division. The disease incidence of Tomato Leaf Curl Virus infecting tomato fields was recorded. TLCV was identified based on symptom expression exhibited by infected plants. Disease incidence from these areas was estimated at about 29.79 % on leaves. TLCV was also confirmed by using several serological techniques and electron microscopy.

Physiology

Growth of plant and crop yield are adversely affected by various abiotic stresses, and they trigger different biochemical processes and physiological responses which might introduce tolerance to these stresses (Hasegawa et al., 2000). Neog et al. (2013) suggested that enzymes are responsible for controlling biochemical reactions, and specific genes are involved in enzyme synthesis, if any change occurs in the enzyme activity would imitate the pattern of gene expression and resultant metabolic procedures in the cell. Wobbes (2004) described that sugars play fundamental roles in the plant's life cycle. The sugar-regulating process is responsible for the inhibition of photosynthesis. When carbohydrates got accumulated in mature source leaves, suppression of genes involved in photosynthesis is witnessed, and consequently, photosynthesis is lessened. Hemida (2005) stated that plant viruses are responsible for causing certain changes in the chlorophyll contents of infected plants which result in the degradation of chlorophyll. Tajul et al. (2011) explained that when viruses' various biochemical changes infect plants occur in plants lowering the quality and quantity of crop. Many reports recommend that virus duplication inside the cell of plant changes different biochemical components of plants and disturb various physiological process occurring inside the plant, for example, photosynthesis, transpiration and respiration of the plants. Khalil et al. (2014) narrated that tomato plant infected by TYLCV caused a significant decrease in the amount of soluble sugar, insoluble sugar and total contents carbohydrate in stem and leaves and these proportions add up in root system when compared with reference control.

Management of TLCV

Through different strategies, TLCV can be managed by according to Iftikhar et al., (2020) with slight modifications techniques mentioned in Figure 2.

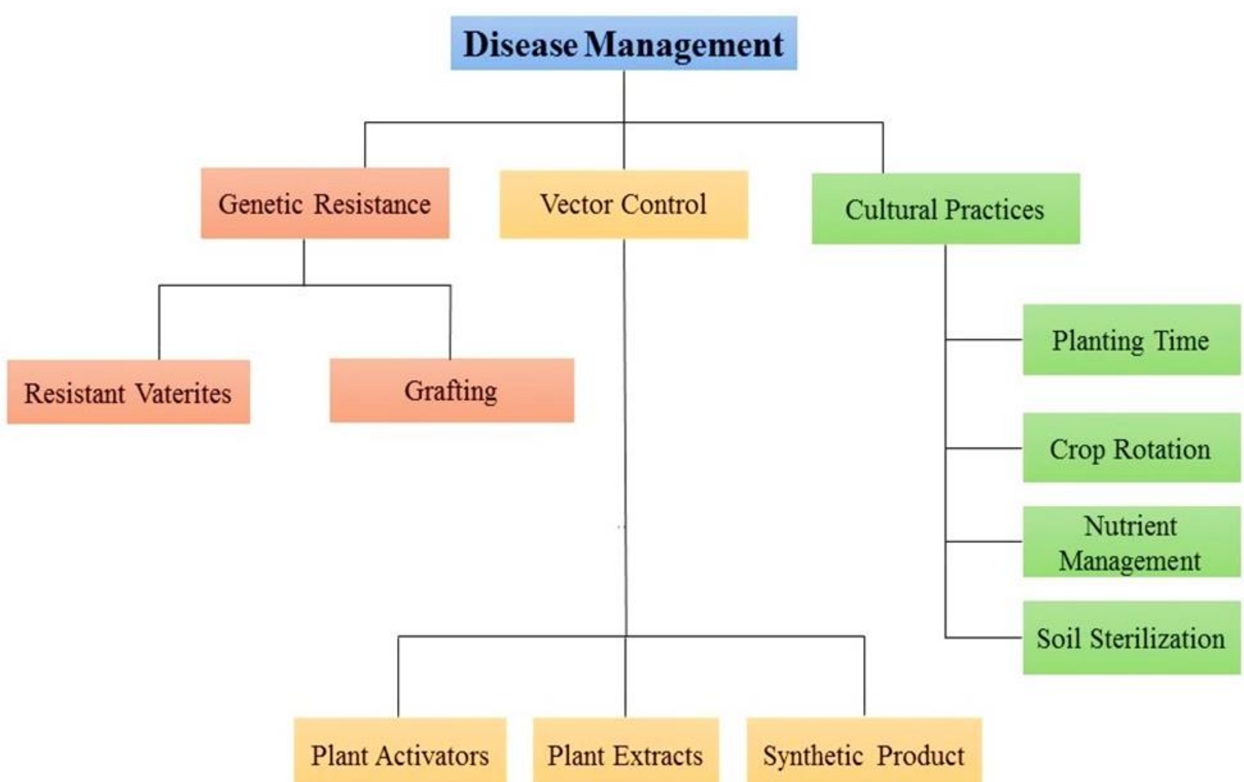

Figure 2. Disease management strategies for the control of TLCV.

Screening

Breeding of cultivars resistant to TLCVD are the possible solution to this disease (Picó et al., 1998). Imran et al. (2013) screened out seven pepper lines to check resistance or tolerance against TLCV. Pepper lines (*Capsicum annuum*) were inoculated under controlled conditions with Tomato Leaf Curl Virus. After seven days of inoculation, symptoms appeared. The most common symptoms perceived were downward curling of leaves and stunted growth of plants. The severity of symptoms was compared with ELISA values. All lines contained high values of ELISA and proved to be highly susceptible except PBC-491, which illustrated only mild symptoms. Rizvi et al. (2000) screened out numerous tomato cultivars to test their resistance against Tomato Leaf Curl Virus. Amongst screened cultivars, the cultivars Fiona, TY King Top 21 were found to be highly resistant against TLCV. The cultivar Mehana was found to be susceptible against TLCV but still able to give good yield, which indicated that along with tolerance against TLCV it had the high yielding ability.

Pilowsky and Cohen (2000) screened out twenty-five wild accessions of tomato crop to check resistance against whitefly borne TYLCV in the greenhouse. About 7 out of 9 accessions of *Lycopersicon peruvianum* were found to be extremely resistant whereas seven accessions of *L. hirsutam* and three accessions of *L. pimpinellifolium* were susceptible. Moreover, CIAS 27 (*L. pimpinellifolium)* was moderately resistant. Ragupathi and Narayanaswamy (2000) described that in 1994 they screened out 160 germplasm of tomato against TLCV from Coimbatore, Tamil Nadu and India. They discovered that only two wild species namely *Lycopersicon hirsutum (LA 1353)* and *Lycopersicon hirsutum* F. sp*. Glaboratum* (LA 1223) were resistant against TLCV and showed no symptoms while rest of 157 cultivars expressed more than 50% infection and moderately resistance reaction was recorded. De-Castro et al. (2013) found that tolerant commercial cultivars often failed under austere infection and entailed protection during early growth. Even if these cultivars succeed to tolerate the infection and able to produce a yield in the presence of TYLCV, they still serve as the sites for replication of TYLCV and can be considered as a reservoir of TYLCV for crops.

Cultural Practices

Regardless of the inherent difficulties that are associated with the viruses which are vector-borne, spraying numerous insecticides were evaluated. To manage TLCV insecticides or other cultural practices were adopted by several workers along with growing tolerant or resistant genotypes. Cook (1986) revealed that in current years because of complete dependence on commercial insecticides resulted in the evolution of some biotypes of whitefly that are resistant against insecticides in India. TYLCV can be controlled by eliminating or reducing the initial source of inoculum through uprooting diseased plants. Berlinger et al. (2002) proposed that physical barriers are most common and popular approach being experienced for protection of tomatoes in the Mediterranean from 1990 and other regions (Arsénio et al., 2002). Antignus et al. (2001) narrated that another approach practiced in protected culture is Ultraviolet absorbing plastic films have presented good results. Polston and Lapidot (2007) said that one more approach that is named as rouging is also highly recommended practice and plants exhibiting early symptoms can be detached to decrease the inoculation source inside the fields and lessen secondary spread.

Bio-Products

Berlinger and Lebiush-Mordechi (1996) stated that the use of Azadirachtin and other Limonids were found to be relatively effective for controlling several plant diseases that are diverse. Neem extracts and oil were proved to be most proficient in inhibiting the plant virus.

Synthetic Products

Luitzinsky et al. (1996) studied that during the experiment they laid yellow-brown, silver and black mulch films on two beds of 15 m length. Seedlings of tomato were planted. Each bed was treated after one week of plantation with imidacloprid. The row covered with yellow-brown plastic mulch and treated with imidacloprid showed good results and had a maximum number of healthy plants. Singh et al. (2000) proposed that a significant role can be played by pesticides to manage the vector populations by decreasing the number of their individuals that can acquire and transmit the virus, thus potentially reducing the incidence of disease. Singh et al. (2003) tested the efficacy of ten different insecticides against whitefly in field conditions. The insecticides used were Endosulfan (400 ml/acre), Carbaryl (500 ml/acre), Ethion (400 ml/ acre), Profenfos (880 ml/acre), Triazophos (400 ml/acre), Cypermethrin (600 ml/acre) and Methyl demeton (300 ml/acre). Top, middle and bottom leaves were used to record data of whitefly population. Data were recorded before spray and then on 1st, 3rd, 7th, and 10th day after spray. Profenfos showed best results.

All the other insecticides helped in reducing whitefly population, but Methyl demeton failed to do so. De-Castro et al. (2013) reported that numerous cost-effective measures could be adopted for controlling viral diseases of tomato such as certain cultural practices, manipulation of vector, eradication of inoculum source or Phyto-sanitation measures, resistant varieties, transgenic plants, exclusion of virus or its vector. Shah et al. (2005) examined nine different insecticides and their efficacy in the field. The insecticides used for of leaf curl were namely Monocrotophos, Acephate, Cypermethrin, Quinalphos, Neem Azadirachtin, Dimetholate, Dichlorvos, Methyldemeton and Phosphamidan. It was proposed that by reducing or controlling the population of vector *B. tabaci* leaf curl can be reduced. Holguín-Peña et al. (2007) developed some strategies to avoid whitefly transmission, planting the crop in whitefly-free periods, protect the crops by using row covers, insecticides should be applied as the last strategy which is most widely used. Fanigliulo et al. (2009) proposed that using insecticides like cypermethrin (0.01%) or Dimethoate (0.1%) in the form of sprays can be effective in controlling whitefly.

CONCLUSION

Among viral diseases, tomato leaf curl virus (TLCV) is the most devastating disease-causing virus all over the world. TLCV is the foremost limiting factor in the production of tomato in Pakistan, causing yield losses 30-40%. Whitefly is regarded as a vector of TLCV and is responsible for spreading the disease. The uses of resistant varieties, control of whiteflies, and management of TLCV by different nutrients are considered economical and recommendable means to overcome TLCV disease.

Future Prospects

Continual prevalence of TLCV is considered to be the major cause of low tomato production in the tomato growing regions. In future, these issues need to address: a) To record the incidence and disease severity of TLCV using molecular methods along with the phenotypic characterizations. b) To determine the changes in the physiology of tomato crop due to TLCV. c) To develop eco-friendly management strategies against TLCV. Epidemiology plays a vital role in the spread and development of the disease. Therefore, disease incidence, along with the physiological parameters, should be measured regularly in correlation with the environmental factors like maximum temperature, minimum temperature, relative humidity and rainfall. Photosynthetic, chlorophyll, lycopene and phenolic contents degradation in infected plants. Moreover, regular field surveys should be conducted to know about the emergence of novel severe strains of the virus and to manage it in the first hand.

Author Contribution

All the authors contributed equally to collect the literature and in write-up process.

Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

Antignus, Y., Nestel, D., Cohen, S., Lapidot, M., 2001. Ultraviolet-deficient greenhouse environment affects whitefly attraction and flight-behavior. Environmental Entomology 30, 394-399.

Arias, R., Lee, T., Logendra, L., Janes, H., 2000. Correlation of lycopene measured by HPLC with the L*, a*, b* color readings of a hydroponic tomato and the relationship of maturity with color and lycopene content. Journal of Agricultural and Food Chemistry 48, 1697-1702.

Arooj, S., Iftekhar, Y., Mubeen, M., Ullah, M.I., Sajid, A., Ali, S., Shakeel, Q., Aatif, M., Raza, W., Noorka, I.R., 2019. Effect of environmental factors on biochemical properties of tomato leaf curl virus infected leaves of tomato. Pakistan Journal of Phytopathology 31, 105-111.

Arooj, S., Iftikhar, Y., Kamran, M., Ullah, M.I., Mubeen, M., Shakeel, Q., Zeerak, N., Bilqees, I., 2017. Management of tomato leaf curl virus through non-chemicals in relation to environmental factors. Pakistan Journal of Phytopathology 29, 41-46.

Arsénio, A.F., Neto, E., Ramos, N., Mangerico, S., Fortunato, E., Stigter, L., Fernandes, J.E., Lavadinho, A.M.P., Louro, D., 2002. Control of the *Bemisia tabaci*/Tomato yellow leaf curl virus complex on protected tomato crops in Algarve (Portugal). EPPO Bulletin 32, 31-35.

Bedford, I.D., Briddon, R.W., Brown, J.K., Rosell, R.C., Markham, P.G., 1994. Geminivirus transmission and biological characterisation of *Bemisia tabaci* (Gennadius) biotypes from different geographic regions. Annals of Applied Biology 125, 311-325.

Bedford, I.D., Briddon, R.W., Markham, P.G., Brown, J.K., Rosell, R.C., 1992. *Bemisia tabaci*-biotype characterisation and the threat of this whitefly species to agriculture, Proceedings-Brighton Crop Protection Conference Pests and Diseases-1992 Brighton, November 23-26, 1992. British Crop Protection Council, pp. 1235-1240.

Berlinger, M.J., Lebiush-Mordechi, S., 1996. Physical methods for the control of Bemisia, in: Gerling, D., Mayer, R.T. (Eds.), Bemisia: 1995, taxonomy, biology, damage, control and management. Intercept, Andover, pp. 617-634.

Berlinger, M.J., Taylor, R.A.J., Lebiush-Mordechi, S., Shalhevet, S., Spharim, I., 2002. Efficiency of insect exclusion screens for preventing whitefly transmission of tomato yellow leaf curl virus of tomatoes in Israel. Bulletin of Entomological Research 92, 367-373.

Bertamini, M., Muthuchelian, K., Nedunchezhian, N., 2004. Effect of grapevine leafroll on the photosynthesis of field grown grapevine plants (*Vitis vinifera* L. cv. Lagrein). Journal of Phytopathology 152, 145-152.

Brown, J.K., Coats, S.A., Bedford, I.D., Markham, P.G., Bird, J., Frohlich, D.R., 1995. Characterization and distribution of esterase electromorphs in the whitefly, *Bemisia tabaci* (Genn.)(Homoptera: Aleyrodidae). Biochemical Genetics 33, 205-214.

Cohen, S., Melamed-Madjar, V., 1978. Prevention by soil mulching of the spread of tomato yellow leaf curl virus transmitted by *Bemisia tabaci* (Gennadius)(Hemiptera: Aleyrodidae) in Israel. Bulletin of Entomological Research 68, 465-470.

Cook, M.J.W., 1986. Bemisia tabaci: A literature survey on the cotton whitefly with an annotated bibliography, in: Cock, H.J.W. (Ed.). International institute of Biological Control. Ascd, UK.

Czosnek, H., Ber, R., Antignus, Y., Cohen, S., Navot, N., Zamir, D., 1988. Isolation of tomato yellow leaf curl virus, a geminivirus. Phytopathology 78, 508-512.

Czosnek, H., Ghanim, M., 2012. Back to basics: are begomoviruses whitefly pathogens? Journal of Integrative Agriculture 11, 225-234.

Czosnek, H., Ghanim, M., Ghanim, M., 2002. The circulative pathway of begomoviruses in the whitefly vector *Bemisia tabaci*-insights from studies with Tomato yellow leaf curl virus. Annals of Applied Biology 140, 215-231.

De-Castro, A.P., Julián, O., Díez, M.J., 2013. Genetic control and mapping of Solanum chilense LA1932, LA1960 and LA1971-derived resistance to Tomato yellow leaf curl disease. Euphytica 190, 203-214.

Fanigliulo, A., Comes, S., Crescenzi, A., Momol, M.T., Olson, S.M., Sacchetti, M., Ferrara, L., Caligiuri, G., 2009. Integrated management of tomato yellow leaf curl in protected tomato crops in southern Italy. Acta Horticulturae, 393-396.

Gafni, Y., 2003. Tomato yellow leaf curl virus, the intracellular dynamics of a plant DNA virus. Molecular Plant Pathology 4, 9-15.

Gottlieb, Y., Zchori-Fein, E., Mozes-Daube, N., Kontsedalov, S., Skaljac, M., Brumin, M., Sobol, I., Czosnek, H., Vavre, F., Fleury, F., 2010. The transmission efficiency of tomato yellow leaf curl virus by the whitefly *Bemisia tabaci* is correlated with the presence of a specific symbiotic bacterium species. Journal of Virology 84, 9310-9317.

Green, S.K., Kali, G., 1994. Leaf curl and yellowing viruses of pepper and tomato. Overview Technical Bulletin 21.

Gronenborn, B., 2007. The tomato yellow leaf curl virus genome and function of its proteins, Tomato yellow leaf curl virus disease. Springer, pp. 67-84.

Hanley-Bowdoin, L., Settlage, S.B., Orozco, B.M., Nagar, S., Robertson, D., 1999. Geminiviruses: models for plant DNA replication, transcription, and cell cycle regulation. Critical Reviews in Plant Sciences 18, 71-106.

Hanssen, I.M., Lapidot, M., Thomma, B.P.H.J., 2010. Emerging viral diseases of tomato crops. Molecular Plant-Microbe Interactions 23, 539-548.

Harrison, B.D., Liu, Y.L., Khalid, S., Hameed, S., Otim-Nape, G.W., Robinson, D.J., 1997. Detection and relationships of cotton leaf curl virus and allied whitefly-transmitted geminiviruses occurring in Pakistan. Annals of Applied Biology 130, 61-75.

Hasegawa, P.M., Bressan, R.A., Zhu, J., Bohnert, H.J., 2000. Plant cellular and molecular responses to high salinity. Annual Review of Plant Biology 51, 463-499.

Hassan, S., Arif, M., Defoer, T., 1993. Preliminary studies on viral diseases of tomato in Malakand agency of North West Frontier Province [NWFP] Pakistan. Sarhad Journal of Agriculture 9, 181-186.

Hemida, S.K., 2005. Effect of bean yellow mosaic virus on physiological parameters of *Vicia faba* and *Phaseolus vulgaris*. International Journal of Agriculture and Biology 7, 154-157.

Holguín-Peña, R.J., Rivera-Bustamante, R.F., Carrillo-Tripp, J., 2007. Pepper golden mosaic virus and related geminiviruses affecting tomato crops. Characterization, Diagnosis & Management of Plant Viruses Vol 3: Vegetable and Pulse Crops, pp. 163-193.

Hull, R., Davies, J.W., 1992. Approaches to nonconventional control of plant virus diseases. Critical Reviews in Plant Sciences 11, 17-33.

Imran, M., Khan, M.A., Fiaz, M., Azeem, M., Mustafa, M., 2013. Influence of environmental conditions on tomato mosaic virus disease development under natural condition. Pakistan Journal of Phytopathology 25, 117-122.

Khalil, R.R., Bassiouny, F.M., El-Dougdoug, K.A., Abo-Elmaty, S., Yousef, M.S., 2014. A dramatic physiological and anatomical changes of tomato plants infecting with tomato yellow leaf curl germinivirus. International Journal of Agricultural Sustainability 10, 1213-1229.

Khan, I.A., 1997. Occurrence, distribution, host range, symptomology and purification of ToMV on tomato. Pakistan Journal of Zoology 29, 385-389.

Krause-Sakate, R., Redondo, E., Richard-Forget, F., Jadão, A.S., Houvenaghel, M., German-Retana, S., Pavan, M.A., Candresse, T., Zerbini, F.M., Le-Gall, O., 2005. Molecular mapping of the viral determinants of systemic wilting induced by a Lettuce mosaic virus (LMV) isolate in some lettuce cultivars. Virus Research 109, 175-180.

Lapidot, M., 2007. Screening for TYLCV-resistance plants using whitefly-mediated inoculation. Tomato Yellow Leaf Curl Virus Disease. Springer Netherlands, 329-342.

Lapidot, M., Friedmann, M., Pilowsky, M., Ben-Joseph, R., Cohen, S., 2001. Effect of host plant resistance to Tomato yellow leaf curl virus (TYLCV) on virus acquisition and transmission by its whitefly vector. Phytopathology 91, 1209-1213.

Luitzinsky, U., Hama, M., R., R., 1996. The use of colored plastics to reduce the incidence of tomato yellow leaf curl virus in market tomatoes. . Horticulture 112, 21-22.

Mansoor, S., Khan, S.H., Saeed, M., Bashir, A., Zafar, Y., Malik, K.A., Markham, P.G., 1997. Evidence for the association of a bipartite geminivirus with tomato leaf curl disease in Pakistan. Plant Disease 81, 958-958.

Matthews, R.E.F., 1991. Relationships between plant viruses and invertebrates. Plant Virology 3, 520-561.

McGregor, C.E., Miano, D.W., LaBonte, D.R., Hoy, M., Clark, C.A., Rosa, G.J.M., 2009. Differential gene expression of resistant and susceptible sweetpotato plants after infection with the causal agents of sweet potato virus disease. Journal of the American Society for Horticultural Science 134, 658-666.

Melzer, M.J., Ogata, D.Y., Fukuda, S.K., Shimabuku, R., Borth, W.B., Sether, D.M., Hu, J.S., 2010. First report of Tomato yellow leaf curl virus in Hawaii. Plant Disease 94, 641-641.

Moriones, E., Navas-Castillo, J., 2000. Tomato yellow leaf curl virus, an emerging virus complex causing epidemics worldwide. Virus Research 71, 123-134.

Mubeen, M., Iftikhar, Y., Ullah, M.I., Shakeel, Q., Aatif, M., Bilqees, I., 2017. Incidence of Okra Yellow Vein Mosaic disease in relation to insect vector and environmental factors. Environment & Ecology 35, 2215-2220.

Mughal, S.M., 1985. Viral diseases of tomato and their control. Progressive Farming.

Navot, N., Pichersky, E., Zeidan, M., Zamir, D., Czosnek, H., 1991. Tomato yellow leaf curl virus: a whitefly-transmitted geminivirus with a single genomic component. Virology 185, 151-161.

Neog, B., Yadav, R.N.S., Singh, I.D., 2013. Peroxidase, polyphenol oxidase and acid phosphatase activities in the stigma-style tissue of *Camellia sinensis* (L) O. Kuntze following compatible and incompatible pollination. Journal of the Indian Institute of Science 84, 47.

Padidam, M., Beachy, R.N., Fauquet, C.M., 1995. Tomato leaf curl geminivirus from India has a bipartite genome and coat protein is not essential for infectivity. Journal of General Virology 76, 25-35.

Perring, T.M., Cooper, A.D., Rodriguez, R.J., Farrar, C.A., Bellows, T.S., 1993. Identification of a whitefly species by genomic and behavioral studies. Science 259, 74-77.

Picó, B., Díez, M.J., Nuez, F., 1998. Evaluation of whitefly-mediated inoculation techniques to screen

Lycopersicon esculentum and wild relatives for resistance to tomato yellow leaf curl virus. Euphytica 101, 259-271.

Pilowsky, M., Cohen, S., 2000. Screening additional wild tomatoes for resistance to the whitefly-borne tomato yellow leaf curl virus. Acta Physiologiae Plantarum 22, 351-353.

Polston, J.E., Lapidot, M., 2007. Management of Tomato yellow leaf curl virus: US and Israel perspectives, Tomato yellow leaf curl virus disease. Springer, pp. 251-262.

Ragupathi, N., Narayanaswamy, P., 2000. Screening of tomato germplasm to tomato leaf curl virus (TLCV) disease. Madras Agricultural Journal 87, 715-717.

Raja, M.B., Khokhar, K.M., 1993. Post-harvest horticulture technology and its future Prospects Proceeding of first international horticulture seminar, January 1992, Pakistan Agricultural Research Council, Islamabad, pp. 265-277.

Rana, N.H., Rao, S.A., Qureshi, M.A., Jilani, M.B., 1992. Occurrence and identification of viruses on tomato plants in Sindh, Pakistan. Pakistan Phyton 4, 54-63.

Rizvi, S.A., Azam, K.M., Zouba, A., 2000. Screening of tomato cultivars against whitefly, *Bemisia tabaci* (Gennadius) and tomato leaf curl virus. Shashpa 7, 143-149.

Saha, A.K., Nath, P.S., De, B.K., Mohasin, M.D., 2005. Effect of different insecticides on the control of whitefly (*Bemisia tabaci* Genn.) population, incidence of chili leaf curl virus and yield of chilli in the plains of West Bengal. . Pestology 29, 24-27.

Saikia, A.K., Muniyappa, V., 1989. Epidemiology and control of tomato leaf curl virus in Southern India. Tropical Agriculture 66, 350-354.

Sainju, U.M., Singh, B.P., Rahman, S., Reddy, V.R., 1999. Soil nitrate-nitrogen under tomato following tillage, cover cropping, and nitrogen fertilization. Journal of Environmental Quality 28, 1837-1844.

Sánchez-Campos, S., Martínez-Ayala, A., Márquez-Martín, B., Aragón-Caballero, L., Navas-Castillo, J., Moriones, E., 2013. Fulfilling Koch's postulates confirms the monopartite nature of tomato leaf deformation virus: A begomovirus native to the New World. Virus Research 173, 286-293.

Shah, S.L., Tsai, W.S., Green, S.K., Khalid, S., Ahmad, I., Rezaian, M.A., Smith, J., 2005. Molecular characterization of tomato and chili leaf curl begomoviruses from Pakistan. Plant Disease 2, 200.

Shelat, M., Murari, S., Sharma, M.C., Subramanian, R.B., Jummanah, J., Jarullah, B., 2014. Prevalence and distribution of Tomato leaf curl virus in major agroclimatic zones of Gujarat. Advances in Bioscience and Biotechnology 5, 1-3.

Singh, B.R., Subhash, C., Shiv, R., 2000. Evaluation of mungbean varieties against yellow mosaic virus. Annals of Plant Protection Sciences 8, 270-271.

Singh, D., Jaglan, R.S., Singh, D., 2003. Relative toxicity of insecticides against white fly (*Bemesia tabaci*). Annals of Biological Sciences 19, 105-107.

Singh, R.K., Rai, N., Singh, M., Singh, S.N., Srivastava, K., 2014. Selection of tomato genotypes resistant to tomato leaf curl virus disease using biochemical and physiological markers. The Journal of Agricultural Science 153, 646-655.

Sugano, J., Melzer, M., Pant, A., Radovich, T., Fukuda, S., Migita, S., Uyeda, J., 2011. Tomato Yellow Leaf Curl Virus-Resistant Varieties for Commercial Production. Plant Disease 78.

Tajul, M.I., Naher, K., Hossain, T., Siddiqui, Y., Sariah, M., 2011. Tomato yellow leaf curl virus (TYLCV) alters the phytochemical constituents in tomato fruits. Australian Journal of Crop Science 5, 575-581.

Tariq, M., 1999. Molecular identification of tomato leaf curl virus in Pakistan and development of transgenic resistance in a model system, Department of Biological Sciences. Quaid-e-Azam University, Islamabad, Pakistan.

Wobbes, B., 2004. Control of plant carbohydrate partitioning by the Arabidopsis thaliana ATB2 bZIP transcription factor gene, Univ. Utrecht, Padualaan 8, 3584 CH, Utrecht, The Netherlands, 106.