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EVALUATION OF TOMATO GENOTYPES AGAINST *TOMATO MOSAIC VIRUS* (ToMV) AND ITS EFFECT ON YIELD CONTRIBUTING PARAMETERS

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Abstract

The use of resistant varieties is an effective, economic and environment friendly management of plant diseases particularly those caused by viruses. This paper reports, evaluation of 21 different tomato genotypes to find out resistance sources against Tomato mosaic virus (ToMV) and to study effect of the virus on yield contributing parameters. The virus identity was confirmed both by Direct Antibody Coating Enzyme Linked Immunoassay (DAC-ELISA) and differential host assay. Characteristic necrotic lesions were observed on differential hosts viz., *Nicotiana tabacum* var. White burly and *Chenopodium amaranticolor* after10 and 3-4 days of inoculation, respectively. Upon ToMV inoculation, plants of accession No. 017902 developed no symptoms and were rated as highly resistant. Its resistance was further confirmed by both DAC-ELISA and indicator host assay, while the remaining genotypes displayed a range of symptoms. Plants of accession No. 017883 showed lowest percent disease index (PDI) and were rated as resistant, while plants of cultivar Red jumbo showed maximum PDI (44.97%) and were rated as susceptible. In susceptible genotypes average ELISA absorbance A_{405} value (2.19) was found higher than resistant one (1.05), while in control healthy plants ELISA absorbance A_{405} was 0.18. Maximum virus titre 2.73 and 0.91 were found in leaf and root tissues of cultivar Red jumbo, respectively. Among tested genotypes, one was highly resistant, one resistant, four moderately susceptible and 15 were susceptible. The virus significantly ($p \leq 0.05$) reduced the yield contributing parameters i.e. plant height, fresh shoot and root weight, dry shoot and root weight in susceptible genotypes.

Key word: ToMV, Mosaic, DAC-ELISA, Titre, Genotypes.

Introduction

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop, belongs to family Solanaceae and ranks second in consumption after potato. Tomato is grown as winter and summer vegetable all over the world (Chowdhury, 1979). It is an opulent source of Lycopene, potassium, iron and vitamins A, B, C (Di Mascio *et al*., 1989; Baloch, 1994) and is useful in prostate cancer (Giovannucci *et al*., 1995; Giovannucci, 1999). In Pakistan area under tomato cultivation is 52,300 hectares with a total production of 529,600 tones having 10.1 tones average yield per hectare (Anon., 2012). Pakistan ranks at 35th position among the tomato producing countries (Anon., 2011), however, this crop in Pakistan is confronted with a number of biotic and abiotic stresses contributing to the low yield than its potential (Saleem *et al.,* 2016; Akhtar *et al.,* 2017). Among biotic factors, diseases caused by viruses are of great importance. About 130 viruses are known to infect tomato worldwide (Hanssen *et al*., 2010) and they can cause 20-90% losses (Hameed, 1995). Among tomato viruses at least seven are known to be present in Pakistan; *Tomato mosaic virus* (ToMV), *Tomato yellow top virus* (TYTV), *Potato virus X* (PVX), *Tomato spotted wilt virus* (TSWV), *Tomato leaf curl virus* (TLCV), *Tomato ring spot virus* (TRSV) and *Cucumber mosaic virus* (CMV) (Mughal, 1985, Khalid *et al*., 2010). The most common and important virus normally associated with tomato crop is ToMV and is dispersed throughout Pakistan (Khan, 1997). ToMV is a definite member of genus tobamovirus (Francki *et al*., 1985), and belongs to family Virgaviridae (King, 2011). It is a stable RNA virus infecting plant species and is wide-spread in distribution (Hollings & Hottinga, 1976). Infected tomato plants generally show mosaic, curling and distortion of leaves, with internal browning and uneven ripening of fruits. ToMV provokes a serious disease in tomato plants reducing yield drastically in susceptible cultivars. Giri and Mishra, (1990) studied the effect of *Tomato mosaic virus* on tomato crop where it was observed to cause 34.30% and 59.77% reduction in number and weight of tomato fruit, respectively. In Pakistan, an average incidence of 29.79% and 25.49% of ToMV was recorded in tomato leaves and seeds, respectively (Khan *et al*., 1997). Similarly, Ali and Hassan, (2002) reported ToMV incidence 16.5-51.3% and 26.1-41.3% in tomato nurseries and tomato fields, respectively. Resistant varieties have been considered as the most efficient control of plant diseases especially those caused by viruses (Tewari & Ramanujam, 1994). Resistance genes against ToMV; Tm-1, Tm-2 and Tm-2^2 have been used in breeding for resistance and are introduced into cultivated tomatoes (Smith & Ritchie, 1983). Varieties like Carmello, Florist and Forest have been reported to be resistant to ToMV (Hameed *et al*., 1991; Ali & Hassan, 2002). Keeping in view the relative importance of the use of resistant varieties to manage viral diseases the study was initiated to find out resistance sources in tomato local genotypes against ToMV and effect of the virus on yield contributing parameters of genotypes having different resistance level.

Materials and Methods

ToMV isolates collection and confirmation: Farmer fields were surveyed to collect the prevalent isolate of ToMV in tomato growing areas of Malakand, Khyber Pakhtunkhwa. Samples were collected from winter grown

tomato in the month of November 2013, based on expression of typical symptoms on the plant leaves under natural field conditions. Collected leaf samples were bagged, labeled properly and transported to the laboratory of Plant Pathology, University of Agriculture, Peshawar, for further studies. DAC-ELISA was used to detect ToMV in infected tomato samples collected during survey. Antigen was prepared by triturating the leaf sample in carbonate coating buffer (1:10 w/v) in plastic bags and wells of micro titration plates were loaded with 100 µl of extract. Subsequently in a humid chamber the plates were incubated overnight at 4°C. Plates were washed three times with 100 µl washing buffer per well after incubation in each step. In antibody buffer virus specific antiserum was diluted at 1:2000 ratio and 100 µl were loaded to each well and were incubated for 2 hours at 37°C. After plates incubation and washing, in antibody buffer goat anti-rabbit conjugate was diluted at 1:2000 ratio and per well an aliquot of 100 µl was loaded and incubated for 2 hours at 37°C. P-nitrophenyl phosphate (PNPP) was dissolved in substrate buffer 1mg/ml and 100 µl were loaded per well. Plates were covered with aluminium foil and were incubated at room temperature in dark. After 45 minutes plates were examined both visually to record colour development and at 405 nm by using ELISA microplate reader (TC-TECO Diagnostic USA). Tomato samples were characterized as ToMV positive by yellow colour development and absorbance three times greater than that of negative control. Virus presence in DAC-ELISA positive samples were further confirmed by inoculation on indicator plants and were further used in screening experiment. The viability and virulence of ToMV was checked on indicator host plants. To separate ToMV from TMV differential host *Nicotiana tabacum* var. White burly and *Chenopodium amaranticolor* were used. With the help of pestle and mortar ToMV infected leaf material were triturated in phosphate buffer (0.01 M, pH 7) at ratio of 1:10 (w/v) and was passed through double layered muslin cloth to remove leaf debris. Carborundom dusted differential and indicator hosts were mechanically inoculated with ToMV infective sap. Negative controls were inoculated with phosphate buffer only. Identified virus isolate was mechanically inoculated and propagated in healthy tomato cv. Riogrande seedlings and were maintained under screen house condition.

Screening of tomato genotypes: Twenty one different tomato genotypes obtained from Plant Genetic Resources Institute at National Agriculture Center (PGRI-NARC) Islamabad and Agriculture Research Institute (ARI) Tarnab, Peshawar, were grown in pot under screen house to evaluate their resistance against the prevalent isolate of ToMV. Uniform and healthy 30 days old nursery plants were transplanted into earthen pots filled with the sterilized potting soil and were allowed to establish prior to the virus inoculation. Mechanical inoculations were performed by following standard mechanical transmission protocol (Dijkstra and de-Jager, 1998). For this purpose ToMV infected leaves were grounded in pestle and mortar containing phosphate buffer (0.01 M, pH 7) at ratio of 1:10 (w/v) and was passed through double layered muslin cloth to remove leaf debris. Tomato plants were dusted lightly with 600-mesh carborundum powder and were mechanically inoculated with infective sap with forefinger. To avoid disease escape plants were re-inoculated after 48 hours of inoculation. Negative controls were inoculated with phosphate buffer only.

Data collection: Data on appearance of symptoms onto inoculated plants were recorded on individual tomato plants in the screen house following modified disease severity scale proposed by Imran *et al*. (2013). Samples were collected from inoculated tomato genotypes four weeks post inoculation for DAC-ELISA. Disease severity data were taken five times post inoculation at weekly interval to calculate percent disease index (PDI). The severity scale rating values were transformed to PDI using the following formula;

$$PDI = \frac{\Sigma n}{4N} \times 100$$

where: n= individual ratings, N= Total number of leaves per plant, 4= maximum rating

Percent reduction in yield contributing parameters: For the growth contributing characters percent decrease was calculated by using the formula of Farooq & Akanda (2007), given bellow:

$$P = \frac{A-A1}{A} \times 100$$

P = Percent decrease of growth contributing character
A = Any growth (yield) contributing trait of control (healthy) plants
A1 = Any growth (yield) contributing trait of infected plants

Percentage of infected plant was considered as response and genotypes were taken as treatment. Completely randomized design (CRD) was used in the screening experiment with four replications and a control. Means were calculated and all the recorded data were subjected to statistical analysis using Analysis of Variance (ANOVA). Mean were separated by using Least Significant Differences (LSD) test (Steel *et al.*, 1997).

Results

Leaf samples collected from tomato plants showing characteristic virus symptoms were assayed and confirmed through DAC-ELISA for the presence of ToMV and/or TMV. Samples that tested positive only against ToMV were carried for further analysis and screening of tomato germplasm. Upon ToMV inoculation on indicator hosts, the plants displayed characteristic virus symptoms with some variability in symptoms development and lesion size formation. Small yellowish lesions were observed six days post inoculation on *N. tabacum* var. White burly. Small yellowish lesions were observed six days post inoculation on *N. tabacum* var. White burly Fig. 1(a). After 10 days post inoculation (dpi) these yellowish lesions turned necrotic having 1mm size regarded as characteristic symptom of ToMV on *N. tabacum* var. White burley, while buffer inoculated plants were symptomless. On *C. amaranticolor* 2.5 mm size necrotic lesions were developed after 3 to 4 dpi Fig. 1(b).

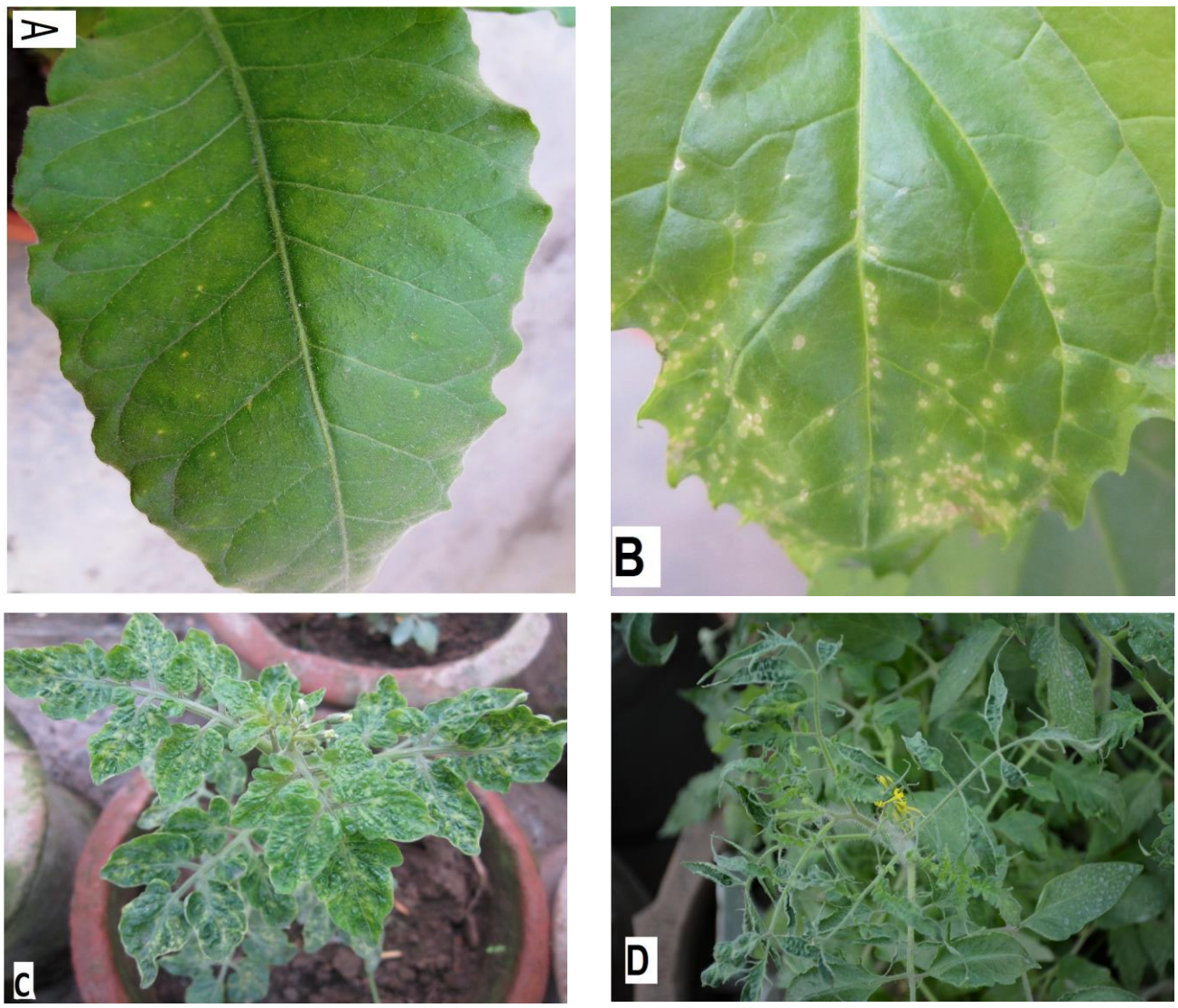

Fig. 1. Local lesions observed on differential hosts, yellowish and necrotic lesion on *N. tabacum* var. White burly (A), necrotic lesion on *C. amaranticolor* (B), mosaic, mottling, narrowing and deformation of ToMV infected tomato leaves(C and D).

Disease severity and symptomatology: Disease severity data were recorded five times at weekly interval. Analyzed data exhibited significant differences ($p \leq 0.05$) among tomato cultivars and accessions for disease severity which ranged from 15.34-44.97% (Table 1) as compared to negative control (buffer inoculated healthy tomato plants). High PDI was observed in majority of tomato accessions and all the tested cultivars. Accession No. 017902 remained the most resistant against ToMV infection among all the tested genotype, followed by accession No. 017883, 006232 and 017858 with 15.34%, 23.93% and 27.30% disease severity, respectively. Cultivar Red jumbo and Roma exhibited maximum disease severity of 44.97% and 39.82% and were rated as susceptible. Disease severity increased significantly and intensified with the passage of time. This increase in PDI was observed with the passage of time in all the tested genotypes (except 017902) and showed maximum PDI five weeks post inoculation (Fig. 2). Accession number 017902 remained symptomless throughout the experiment which was further confirmed by DAC-ELISA and indicator host assay on *N. tabacum* var. *xanthi.* Infected tomato genotypes showed variability in symptoms development under screen house condition. Depending on genotypes symptoms observed were leaf mosaic, mottling, yellowing, narrowing, distortion, curling and reduction in leaf size.

DAC-ELISA absorbance values in leaves and roots tissue of tested genotypes: The observed variations among treatments for ELISA absorbance were significant (Table 1). Leaf samples were rated as positive with A_{405}values greater than (0.54), while they were considered as negative with A_{405} less than (0.54). For roots ELISA test, samples were rated positive with A_{405}values greater than 0.12, and were negative with A_{405} less than 0.12. An average ELISA absorbance of 2.04 was observed in tomato leaves which were higher than buffer inoculated plants samples absorbance measuring (0.182). The highest (2.73) absorbance was observed in Red jumbo, followed by accession No. 19843 (2.56) and Roma-vf (2.54). Virus titre was low in root tissues where the average absorbance was 0.549 as compared to 2.04 calculated in leaf tissues of same inoculated plants (Table 1). The highest absorbance in ELISA assay for the root tissues were observed in case of Red jumbo (0.91), followed by accession No. 17880 and 19843 with absorbance of 0.79 and 0.76, respectively.

Table 1. Percent disease index (PDI), resistance level and ELISA absorbance (A_{405}) shown by different tomato accessions and cultivars against ToMV.

Genotypes	PDI	Rating scale	Host response	ELISA absorbance (A_{405})	
				Leaf tissues	Root tissue
006231	35.64 cd	3	S	2.23 bcd	0.67 cde
006232	23.93f	2	MS	1.92 cde	0.42 gh
006234	38.63 bcd	3	S	2.03 cde	0.56 defgh
017858	27.37 ef	2	MS	2.27 bcd	0.74 bcd
017872	37.20 bcd	3	S	1.83 de	0.46 efgh
017878	39.11 bc	3	S	2.09 cde	0.43 gh
017880	30.44 e	2	MS	2.21bcde	0.79 bc
017882	36.71 bcd	3	S	2.24 bcd	0.56 defgh
017883	15.34 g	1	R	1.05 f	0.35 h
017889	35.77 cd	3	S	1.96 cde	0.45 fgh
017902	0.00 h	0	HR	0.24 g	0.03 i
017903	30.33 e	3	S	1.79 e	0.56 defgh
019841	35.82 cd	3	S	2.10 cde	0.61 cdefg
019842	36.34 bcd	3	S	2.18 bcde	0.50 efgh
019843	28.78 e	2	MS	2.56 ab	0.76 bcd
019844	39.00 bcd	3	S	2.19 bcde	0.57 defg
Roma-vf	38.95 bcd	3	S	2.54 ab	0.57 defg
Red jumbo	44.97 a	3	S	2.73 a	0.91 ab
Roma	39.82 b	3	S	2.01 cde	0.65 cdef
Riogrande	35.21 c	3	S	2.31 abc	0.45 fgh
Riogrande-clxvf	35.93 cd	3	S	2.29 abc	0.51 efgh
Buffer inoculated	0.00 h	0		0.18 g	0.04 i
Positive control				2.18 bcde	1.11 a

R; Resistant; MS: Moderately susceptible; S: Susciptable

$LSD_{(0.05)(\text{Mean disease severity})} = 3.86$

$LSD_{(0.05)(\text{ELISA A405}) \text{ Leaf tissues}} = 0.44$

$LSD_{(0.05)(\text{ELISAA405}) \text{ Root tissues}} = 0.21$

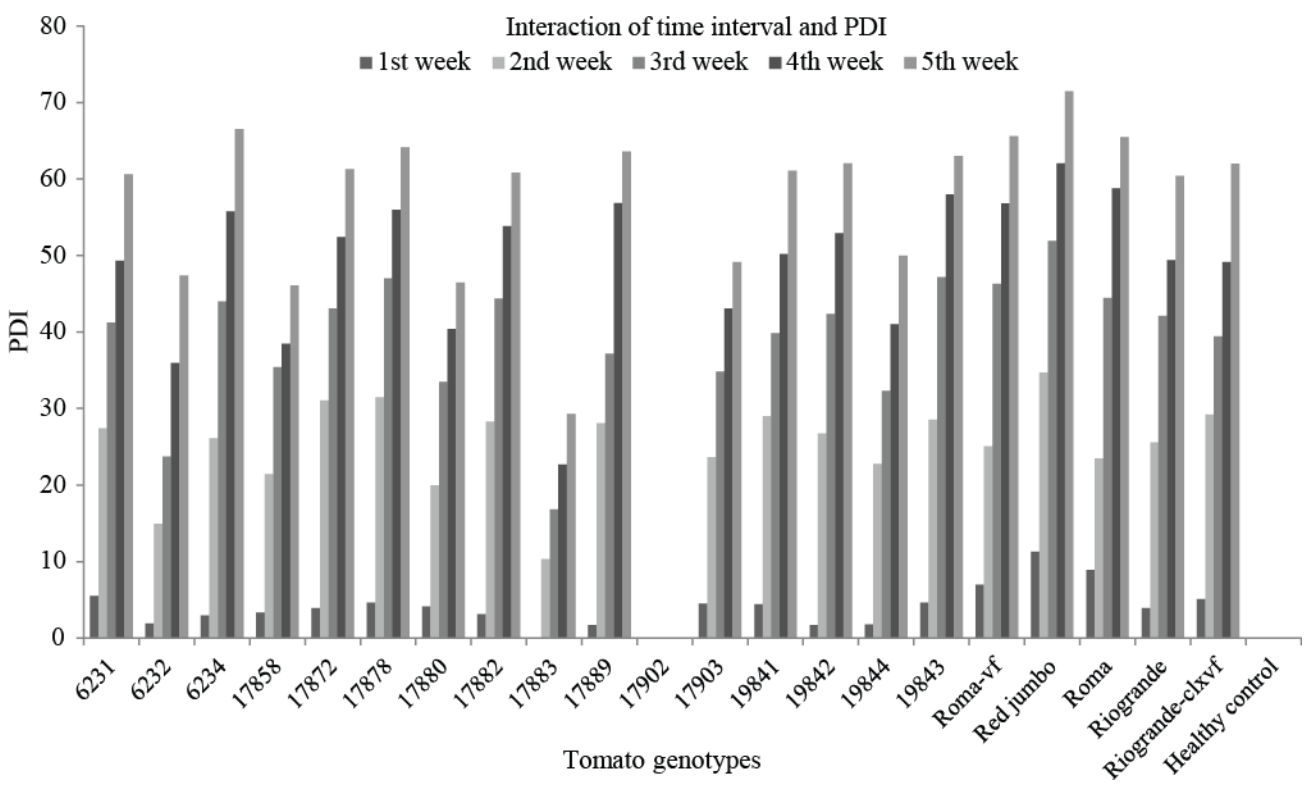

Fig. 2. Interaction of time interval and PDI.

Table 2. Plant height (cm) and Percent reduction over healthy control of different accessions and cultivars of tomato in response to ToMV infection.

Tomato genotypes	Plant height		PROHC
	Inoculated plants	Control healthy plants	
006231	56.82 cd	71.60	20.63
006232	60.85 b	81.50	25.33
006234	54.65 d	86.60	36.89
017858	54.80 d	69.00	20.57
017872	37.25 i	64.20	41.96
017878	56.60 cd	78.00	27.43
017880	22.07 j	40.20	45.08
017882	42.45 fgh	69.30	38.74
017883	60.72 b	71.00	14.47
017889	48.50 e	72.40	33.01
017902	67.80 a	69.20	2.02
017903	44.50 f	70.00	36.42
019841	43.50 fg	65.00	33.07
019842	43.35 fg	87.00	50.17
019843	58.35 bc	84.00	30.53
019844	51.10 e	68.60	25.51
Roma vf	38.40 i	72.20	46.81
Red jumbo	40.50 ghi	71.00	42.95
Roma	43.00 fgh	74.20	42.04
Riogrande-clxvf	39.67 hi	70.80	43.96
Riogrande	39.10 i	74.00	47.16

PROHC= Percent reduction over healthy control

$LSD_{(0.05)(Plant\ height)}$= 3.33

Effect of ToMV infection on plant height (cm): Since the differences among genotypes were significant ($p \leq 0.05$) for plant height under severe disease pressure, indicating significant effect of ToMV on plant height (Table 2). In virus stressed condition the highest plant height among all the genotypes were shown by 017902 (67.80 cm), while, the shortest plant height was recorded for the genotype 17880 (22.07 cm). In case of healthy control, highest plant height was recorded as compared to their respective treatments (Table 2). In virus stressed plants, there was 14.47-50.17 percent decrease in plant height in comparison with healthy control. Severe effects of 50.17% and 47.16% decrease in plant height were observed in genotypes 19842 and Riogrande, respectively. While lower effect in plant height was observed in genotypes 17883 and 17858 with 14.47% and 20.57% decrease, respectively.

Effect of ToMV infection on plant fresh shoots weight (g): Significant ($p \leq 0.05$) reductions in fresh plant shoot weight were manifested by different tomato genotypes infected by the virus (Table 3). There was 26.92 to 58.87% reduction in fresh shoot weight over healthy control, depending upon the genotypes. Genotype, Roma-vf was found to be the most sensitive, while 17883 was the least sensitive. Fresh shoot weight reduction over control was maximum in Roma-vf (58.87%), followed by accession No. 19842 (55.10%) and Riogrande (51.07%), respectively. Conversely, shoot weight reduction was minimum in accession No. 17883 (26.92%). Control of each treatment produced higher fresh weight than their respective treatments.

Table 3. Plant fresh, dry shoot weight (g) and Percent reduction over healthy control of different accessions and cultivars of tomato in response to ToMV infection.

Genotypes	Fresh shoot weight		Dry shoot weight		Fresh shoot weight PROHC	Dry shoot weight PROHC
	Inoculated plants	Healthy control	Inoculated plants	Healthy control		
6231	33.33gh	64.30	06.68fgh	13.18	48.16	49.31
6232	41.20c	74.50	07.83cde	13.79	44.68	43.18
6234	41.67c	76.90	08.54c	16.88	45.81	49.40
17858	36.06ef	63.87	07.44def	11.37	43.54	34.52
17872	32.93gh	61.20	05.98h	11.68	46.18	42.93
17878	39.67cd	72.84	07.98cd	12.96	45.53	38.38
17880	27.57i	43.70	06.47gh	10.25	36.91	36.87
17882	33.85fgh	62.13	06.80fgh	11.20	45.51	39.24
17883	46.23b	63.27	09.75b	12.89	26.92	24.36
17889	41.39c	72.27	08.46c	16.20	42.72	47.74
017902	67.12a	65.90	14.7a	14.18	01.86	04.19
17903	33.70fgh	68.75	07.22defg	13.27	50.97	45.59
19841	35.28efg	61.52	06.79fgh	11.15	42.64	39.10
19842	37.51de	78.63	06.94fg	16.12	55.10	59.24
19843	39.73cd	74.44	07.11efg	15.46	50.34	53.97
19844	40.04cd	68.93	06.97efg	13.02	41.91	46.46
Roma vf	31.75h	77.21	06.18f	13.75	58.87	56.47
Red jumbo	34.33fg	67.26	06.87fg	12.69	48.95	45.82
Roma	35.25efg	71.32	06.57gh	14.32	50.56	51.50
Riogrande-clxvf	33.79fgh	67.4	06.62fgh	13.21	49.86	49.88
Riograndi	36.03ef	73.64	06.94fg	13.94	51.07	50.17

PROHC = Percent reduction over healthy control

$LSD_{(0.05)\ (Fresh\ shoot\ weight)}$ = 2.54

$LSD_{(0.05)\ (Dry\ shoot\ weight)}$ = 0.86

Table 4. Plant fresh root, dry root weight (g) and percent reduction over healthy control of different accessions and cultivars of tomato in response to ToMV infection.

Genotypes	Fresh root weight		Dry root weight		Fresh root weight PROHC	Dry root weight PROHC
	Inoculated plants	Healthy control	Inoculated plants	Healthy control		
006231	5.70 cde	16.00	1.71 defg	5.76	64.37	70.31
006232	5.33 cdef	17.56	1.59 defg	6.23	69.64	74.47
006234	4.87 defg	18.48	1.29 efg	5.35	73.64	75.88
017858	5.42 cdef	17.47	1.64 defg	5.68	68.97	71.12
017872	6.27 cd	14.58	2.10 cd	4.96	56.99	57.66
017878	4.89 defg	19.35	1.63 defg	6.28	74.72	74.04
017880	4.49 efg	11.23	1.23 efg	3.54	60.01	65.25
017882	5.76 cde	14.74	1.88 def	5.03	60.92	62.62
017883	8.72 b	16.81	3.32 ab	5.87	37.84	35.40
017889	4.43 c	12.67	1.41 bc	4.54	65.03	68.94
017902	11.90 a	12.15	4.02 a	4.19	02.05	4.06
017903	5.14 def	13.00	1.68 defg	4.43	60.46	62.07
019841	6.15 cde	22.23	1.93 defg	8.87	72.33	78.24
019842	4.57 efg	20.53	1.22 efg	5.27	77.73	76.85
019843	5.29 cd	12.60	1.40 cde	4.25	58.01	67.05
019844	5.59 cdef	13.56	1.60 defg	5.4	58.77	70.37
Roma-vf	4.40 efg	20.20	1.55 defg	7.17	78.21	78.38
Red jumbo	4.07 fg	18.00	1.19 fg	5.37	77.38	74.73
Roma	4.38 efg	17.80	1.39 defg	6.07	75.39	77.10
Riogrande-clxvf	3.60 g	15.31	1.00 g	4.36	76.48	77.06
Riogrande	3.57 g	14.68	1.02 g	4.24	75.68	75.94

PROHC= Percent reduction over healthy control

$LSD_{(0.05)\ (Dry\ root\ weight)} = 0.72$

$LSD_{(0.05)\ (Fresh\ root\ weight)} = 1.4$

Effect of ToMV infection on plant dry shoot weight (g): Depending on genotypes, percent reduction over healthy control was 24.36 to 59.24 (Table 3). Maximum reduction (59.24%) in dry shoot weight was observed in genotype 19842, while minimum (24.36%) was observed for genotype 17883. Genotypes, Roma-vf, 19843, Roma and Riogrande, suffered from 56.47, 53.97, 51.50, and 50.17% per plant reduction in dry shoot weight, respectively.

Effect of ToMV infection on plant fresh Root weight(g): Significant ($p \leq 0.05$) reductions in fresh root weight were recorded for different tomato genotypes infected by the virus (Table 4). Most sensitive genotype was Roma-vf with 78.21% reduction in fresh root weight, closely followed by accession No. 19842 and Red jumbo with 77.73 and 77.38% reduction of fresh root weight, respectively. Conversely, root weight reduction was minimum in accession No. 17883 (37.84%), while in case of 017902 (2.05%) which was disease free. Maximum root weight was observed for control healthy plants than their respective treatments.

Effect of ToMV infection on plant dry root weight (g): Depending on genotypes, percent reduction over healthy control was 35.40 to 64.71 (Table 4). Maximum reduction of 78.38% in dry root weight was manifested by Roma-vf, while minimum reduction (35.40%) was exhibited by genotype 17883. Genotypes 019841, Roma, Riogrande-clxvf, Riogrande and 006234, suffered from 78.24, 77.10, 77.06, 75.94 and 75.88% reduction in dry root weight, respectively over healthy control.

Discussion

Plant viruses are the major constraint to agriculture production all over the world. The use of resistant varieties is an effective, cheapest and environment friendly approach towards plant disease management (Strange & Scott, 2005), especially those caused by viruses (Tewari & Ramanujam, 1994).

ToMV and TMV are closely related important tobamoviruses causing serious losses in tomato crop. Mixed infection of ToMV and TMV is common in tomato (Alishiri *et al*., 2013) but ToMV is predominant in tomato and is regarded as its preferred host (Chitra *et al*., 1999; Pfitzner, 2006). ToMV and TMV have close serological relationship and it is difficult to differentiate these two viruses on the basis of serological assay. Under present study, ToMV was identified on differential hosts. Necrotic lesions were produced on differential and indicator hosts such as *Nicotiana tabacum* var. White burley and *Chenopodium amaranticolora*, after virus inoculation. Our results are in line with those of Ahoonmanesh & Shalla (1981); Green & Kim (1991); Hollings & Hottinga, (1976), who have reported similar necrotic lesion upon ToMV inoculation. In our study, different tomato genotypes, 15 accessions and five cultivars were tested against ToMV under screen house conditions. Symptoms were started after seven days of inoculation on susceptible genotypes. Resistant genotypes restrict the virus to inoculated leaves, while, in susceptible genotypes the virus spread throughout the inoculated plants within 7 days (Smith & Murakishi, 1993). Genotypes displayed variation in symptom development

and severity. Our results are in line with those of Broadbent (1976); Hollings & Hottinga (1976); Chitra *et al*. (2002); Hoonand Jin (2002), who have also reported similar variation in ToMV symptoms.

Out of 21 genotypes, accession No. 017902 was highly resistant, while accession No. 17883 was rated as resistant. Conversely, all the cultivars and most of the accessions were found susceptible to the virus. Similar results were previously reported by different authors (Hameed *et al*., 1991; Hameed *et al*., 1992; Ali & Hassan, 2002; Imran *et al*., 2013). The present study results shows that, plant height, fresh and dry weight of shoots and roots decreased significantly in ToMV-stressed condition. Infection of ToMV significantly reduces plant height, shoot and root weight (Schuerger & Hammer, 1995; Balogun *et al*., 2002; Pazalar *et al*., 2013). Severe mosaic symptoms and reduced leaf size effect photosynthetic activities and interfere with energy production resulting in stunted plants and decrease in biomass compared to control healthy plants (Farooq &Akanda, 2007; Pazalar *et al*., 2013). Some resistance genes confer extreme resistance (ER), while immunity is conveyed in some cases with no virus multiplication (Barker & Harrison, 1984; Watanabe *et al*., 1987). In effector-triggered immunity (ETI), crucial role is played by the R proteins. In most of the cases R protein interaction with a virulence effectors of pathogen results in HR (Jones & Dangel, 2006), which is rapid death of cells around the pathogen entry point (Thomma *et al*., 2011). While in other cases of R genes conferring extreme resistance (ER), necrotic lesion are not observed either in systemic tissue or at pathogen entry point. Tm-1, Tm-2, Tm-2^2 genes of tomato provide resistance against ToMV (Smith & Ritchie, 1983) and restrict virus multiplication and systemic movement (Smith & Murakishi, 1993). Most of the genotypes including commercially grown tomato cultivars were found susceptible and the virus drastically reduced yield and other related parameters in susceptible genotypes. However, these genotypes were not evaluated for yield performance in virus stress condition. There is a need to test more tomato genotypes against multiple isolates of ToMV at different agro-ecological zone.

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