International Journal of
Agriculture, Environment and Food Sciences

JAEFS

E-ISSN : 2618-5946 DOI: 10.31015/jaefs.2021.4.9

www.jaefs.com

Research Article Int J Agric Environ Food Sci 5 (4): 497-507 (2021)

Evaluation of Eggplant Cultivars for Tomato Spotted Wilt Orthotospovirus (TSWV) Disease Tolerance in Greenhouse Conditions

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Abstract

Eggplant (*Solanum melongena* L.) is widely consumed vegetables like potato and tomato. Worldwide, the eggplant is cultivated in all regions and Turkey is the fourth largest eggplant-producer. It is a rich source of minerals and as a low-calorie fruit. Eggplant plays a vital role having high phenolic content which enhance the radical absorbing capacity. Objective of this study was to evaluate the effect of tomato spotted wilt orthotospovirus (TSWV) on five different eggplant cultivars (Kemer, Aydın Siyahı, Halep Karası, Topan and Silindirik) under greenhouse conditions. Eggplant cultivars were mechanically inoculated with TSWV isolates and tested by DAS-ELISA method. According to DAS-ELISA and visible virus-like symptoms, all tested cultivars were susceptible to TSWV infection and showed typical tospo-like symptoms including concentric ringspot, necrosis, chlorotic ringspot, and necrotic ringspot. The highest infection rate was observed in Kemer (58%) followed by Topan (52%) whereas, the lowest infection rate was noticed in Silindirik (38%). Infection of TSWV caused significant ($p \leq 0.05$) reduction in fruit number (32.99-59.34%), fruit length (17.12-49.76%), fruit diameter (12.44-38.30%), fruit weight (31.31-67.70%), flesh thickness (18.11-46.05%), total soluble solid (16.83-40.69%), fruit color, fruit firmness (4.88-29.25%) and yield (50.22-84.22%) in infected plants. According to the results obtained, the cultivar Silindirik performed better performance against TSWV among all the tested cultivars. Whereas the performance of the Kemer and Topan was poor making them more sensitive to TSWV. These results will help breeders for the development of TSWV resistant varieties by using these tolerant cultivars.

Keywords: Eggplant, cultivar, ELISA, *Tomato spotted wilt orthotospovirus*, Yield, Quality

Introduction

Eggplant (*Solanum melongena* L.) belongs to the family *Solanaceae*, which is widely consumed vegetables like potato, tomato, and pepper. Globally, the eggplant is cultivated in all regions including the subtropical, tropical, and temperate regions (Sihachakr et al., 1994). It is considered as a rich source of minerals and as a low-calorie fruit. Among the top ten vegetables, the eggplant plays a vital role having high phenolic content which enhance the radical absorbing capacity (Cao et al., 1996; Caguiat and Hautea, 2014). Turkey is well-known for its widely cultivated vegetables; eggplant is one of them, which was introduced from Europe by traders during 16th century. Turkey is the fourth largest eggplant-producing with the annual production of 822.659 tons (FAOSTAT, 2019).

Several biotic and abiotic stress factors affect the yield of eggplant. The biotic factors include insect pests and pathogens. Different diseases are developed by bacteria, phytoplasmas, fungi and viruses either in roots or shoots of eggplant (Tsitsigiannis et al., 2008). Eggplant is prone to different kind of diseases (bacterial, fungal, and viral) that affect its productivity and yield. Among the viral diseases which affect eggplant are *Tobacco mosaic virus* (TMV), *Tomato mosaic virus* (ToMV), *Cucumber mosaic virus* (CMV) and *Tomato spotted wilt orthotospovirus* (TSWV) whereas, *Tomato yellow leaf curl virus* (TYLCV) affects tomato and pepper, but eggplant is resistant

Cite this article as:
Alam, A. and Elçi, E. (2021). Evaluation of eggplant cultivars for tomato spotted wilt orthotospovirus (TSWV) disease tolerance in greenhouse conditions. International Journal of Agriculture, Environment and Food Sciences, 5(4), 497-507
Doi: https://doi.org/10.31015/jaefs.2021.4.9
Orcid: Afzal Alam: 0000-0002-1939-9950 and Eminur Elçi: 0000-0002-6434-6321
Received: 23 March 2021 **Accepted:** 06 September 2021 **Published Online:** 17 December 2021
Year: 2021 **Volume:** 5 **Issue:** 4 (December) **Pages:** 497-507
Available online at : http://www.jaefs.com - http://dergipark.gov.tr/jaefs

to this virus (Czosnek et al., 1993). TSWV belongs to the genus *Orthotospovirus* of the family *Bunyaviridae* (Salamon et al., 2016). TSWV disease was reported in 1915 for the first time (Best, 1968). There are a lot of plant families including *Solanaceae*, *Asteraceae*, *Brassicaceae*, *Bromiliaceae* and *Leguminaceae* that are prone to TSWV infections (Momol and Pernezny, 2006). TSWV can be transmitted with the help of different thrips species including *Frankliniella occidentalis*, *F. schultzei*, *F. intonosa*, *F. bispiosa*, *F. fusca*, *Thrips setosus*, and *T. tabaci* and there is no report of it to be seed transmitted (Tsuda, 1999; Mound, 1996). The effect of TSWV on plants varies with type of plant, time, and duration of infection. General symptoms of its infection on plants are wilting, ringspots, stunting of leaves, necrosis, and chlorosis (Holguin-Pena and Rueda Puente, 2007). In eggplant, symptoms such as deformed leaves, necrosis of leaves, molted and stunted plants have been observed (Kamberoglu et al., 2009).

Among the viruses, TSWV can cause systemic infection which lead to yield loss resulting in producing un-marketable plants, flower, and fruit (Ramkat et al., 2006). This virus destroys all flowering crops, and it is currently causing the most severe effects on its host plants around the globe (Pfleger et al., 1989). TSWV was reported to cause 100% yield losses in tomato (Rosello et al., 1996). Currently, the occurrence of TSWV is causing severe problems in vegetable growing areas of Turkey, also in other parts of the world (Kilic et al., 2017). Due to these losses; the current study was conducted to evaluate the performance of selected Turkish eggplant cultivars in response to TSWV effects on yield and quality traits.

Material and Methods

Experimental Site Description

This research work was carried out in the greenhouse of the Faculty of Agricultural Science and Technologies at Niğde Ömer Halisdemir University, Niğde, Turkey during 2019-2020. It is located at 37.97 latitude and 34.68 longitude and 1243 m above the sea level in the Central Anatolia region of Turkey.

Plant Materials and Growth

The most commonly grown five cultivars of eggplant including Topan, Kemer, Halep Karası, Aydın Siyahı and Silindirik were used to evaluate the effects of *Tomato spotted wilt orthotospovirus* infection on eggplants. First, the seeds were sown in trays for germination (n=2). Later seedlings were transplanted to the 10L pot one plant per pot filled with turf and perlite (3:1) and were maintained in greenhouse with daytime and nighttime temperature of 24°C and humidity 60-70%.

Isolation of TSWV and Experimental Design

For TSWV isolate of tomato plant was obtained from the Turkish Ministry of Agriculture and Forestry, Ankara Directorate of Agricultural Quarantine. After transplanting the plants were rub-inoculated with TSWV two times: first at 7th days at three leaf stage and second at 14th day after transplanting the eggplants. Twenty-five plants were used for inoculation and 25 plants were used as a control for each cultivar had total 50 plants; 25 inoculated with TSWV and 25 buffer inoculated (i.e., mock-inoculated control).

Mechanical Virus Inoculation

Mechanical virus (rub)-inoculation method was used for inoculating eggplants. Inoculation buffer having pH: 7.4, containing 0.199 g/l KH_2PO_4, 1.14 g/l Na_2HPO_4 and 0.1% Na_2SO_3 and 1% PVP-40 were prepared. TSWV isolate of tomato plant fresh leaf samples were grinded by mortar and pestle to get leaf extract for inoculum sources and mix these extracts with inoculation buffer in 1/10 ratio. Seedlings were irrigated well and kept under dark conditions one day before inoculation. Plants were inoculated in the morning because the stomatal opening and absorption rate is generally higher as compared to evening. Before starting the inoculation, carborundum was sprinkled on the surface of leaves to cause abrasion of the cells and the virus inoculum source was rubbed over the surface of eggplants leaf by using cotton-swab. Tap water was sprayed on the surface of inoculated leaves after 5 mins of inoculation. For mock inoculations, only the buffer was rubbed on the surface of leaves and these plants were used as mock-control. After 10-15 days of virus inoculation, plants show symptoms of TSWV and for confirmation of the virus; the leaves were collected randomly and tested by ELISA method.

Double Antibody Sandwich Enzyme Linked Immunosorbent Assay (DAS-ELISA)

DAS–ELISA method with the monoclonal antisera of TSWV was performed for detection of TSWV in eggplant according to Clark and Adams (1977). Specific antibodies for applied according to manufacturer instructions (Bioreba AG, Switzerland).

Calculation of Infection Rate of TSWV (%)

Leaf samples were collected from all cultivars as shown in Table 1. Following formula was used for calculation of TSWV infection rate in eggplants to find the infection ratio.

$$TSWV\ (\%) = \frac{Z1}{Z2} \times 100$$

Z1= Positive samples of eggplant tested by ELISA,
Z2= Total samples of eggplants tested by ELISA

Yield and Quality Parameters of Eggplant

Fruits of inoculated and mock-control plants were harvested at the full maturity. Fruit morphological traits related to quality were evaluated for 7-10 ripened fruits per cultivar. The ripened fruits from infected and uninfected plants were harvested by hand and put in plastic bags and the following parameters were analyzed. Fruit numbers (FN) were counted manually. The fruit length (FL) was measured by using measuring tape and data was recorded in centimeter (cm), whereas the fruit diameter (width) was measured by using vernier caliper and data was recorded in millimeter (mm). Fruit fresh weight (FW) and dry matter (DM), the digital scale was used for fresh weight fruits were weighed immediately after harvesting

and for dry matter the samples were put in oven for drying at 70ºC for 48 hours. Fruit color (FC) was determined by Chroma meter describes the color distribution in eggplant cultivars in three dimensions "L", "a" and "b". The dimension "L" was considered since it explains the alteration of color from dark/black to white (light), commonly observed in fruit skin of eggplant Fruit firmness (FF) was measured by using penetrometer (LANATECH-GY-3). Total soluble solid (TSS) (brix) was measured by refractometer. Thickness of fruit flesh was calculated by vernier caliper. Yield (g) per plant was measured by using digital scale.

Statistical Analysis

Analysis of Variance (ANOVA) statistical test was performed using the Statistix 8.1. Duncan multiple comparison test was used to compare the differences between the averages which were statistically significant according to the variance analysis results. Principal component analysis (PCA) and correlation analysis were done by XLSTAT-2014.

Results

Disease Symptoms

The observed symptoms were deformation of the leaves, ringspot, necrosis, necrotic ringspot, and concentric ringspot on inoculated plant leaves as shown in Figure 1. The symptoms of TSWV started to appear on fresh young leaves after 10 to 14 days of first inoculation. Samples were collected from the inoculated plants randomly and tested by DAS-ELISA for the confirmation of TSWV infection. No symptom was developed on infected plants' fruits and mock-control plants.

DAS-ELISA Results

Randomly collected leaf samples from inoculated eggplant cultivars were tested by DAS-ELISA method. According to the ELISA test, the highest infection result was detected from Kemer cultivar 58% followed by Topan 52%, whereas the lowest positive result was observed from Silindirik cultivar 38%. The results of ELISA tests are summarized in the Table 1.

Quantity Traits

Number of Fruits per Plant

It was observed that among the infected plants, cultivar Silindirik resulted in highest number of fruits (5,26), whereas the lowest numbers of fruits were recorded for infected plants of cultivars Aydın Siyahı (1.79), Topan (1.87) and Halep Karası (1.90) which were statistically non-significant from each other. Whereas, for mock-control plants the highest number of fruits was observed for Silindirik (7.85) followed by Kemer (6.47). It was observed that infection of virus significantly reduced the fruit number. Highest percent of reduction in fruit number over control in infected plants was recorded for Topan 59.34%, followed by Kemer 55.33% whereas the lowest percentage of reduction 32.99% was recorded for Silindirik cultivar (Figure 2-A).

Fruit Length

Fruit length of the eggplant cultivars was significantly ($p \leq 0.05$) affected by TSWV. The infected plants comparatively showed lower fruit length while the control showed higher fruit length. Among the infected plants the highest fruit length was recorded for Silindirik (12.59 cm) followed by Aydın Siyahı (8.7 cm). Whereas, among the mock-control plants the highest fruit length was recorded for Silindirik (15.19 cm) and lowest was recorded for Topan (10.36 cm). Tested eggplant cultivar Kemer resulted in highest percent of reduction in fruit length (49.76%), followed by Topan (45.95%) and Aydın Siyahı (41.53%) in infected with respect to their mock-control. Lowest percent decrease in fruit length (17.12%) was recorded for Silindirik which was least effected by TSWV (Figure 2-B).

Fruit Diameter

Significant ($p \leq 0.05$) reduction in fruit diameter was also observed in infected plants as compared to their respective mock-control. Among the infected plants highest fruit diameter (40.96 mm) was recorded from Silindirik followed by Topan (38.93 mm) and lowest was recorded for Kemer (21.31 mm).Whereas, among the mock-control plants the highest fruit diameter was recorded for Topan (52.76 mm) followed by Silindirik (46.97 mm) and lowest was recorded for Halep Karasi (32.72 mm). The highest percent reduction of fruit diameter was calculated from Kemer cultivar (38.30%) followed by Topan (26.21%), whereas Silindirik was least affected and resulted in lowest percent decrease in fruit diameter (12.80%) (Figure 2-C).

Fruit Weight

Fruit weight was significantly ($p \leq 0.05$) affected by TSWV. Among the infected plants the highest fruit weight was recorded for Kemer cultivar exhibited lowest fruit weight (39.45 g) followed by Topan (51.78 g) and Halep Karası (53.65 g) while among the mock-control plants the cultivar Silindirik conferred highest fruit weight (169.49 g) followed by Topan (145.53 g), Aydın Siyahı (127.74 g) and Kemer (122.12 g). The highest percent reduction of fruit weight was calculated from Kemer 67.70% followed by Topan 64.42%, Aydın Siyahı 55.74% and Halep Karası 45.70%, whereas lowest percent reduction was recorded for Silindirik cultivar 31.31% which was less affected by TSWV (Figure 2-D).

Flesh Thickness of Fruit

Flesh thickness was significantly ($p \leq 0.05$) affected by TSWV. Among the infected plants the highest flesh thickness was recorded for Silindirik (8.00 mm) followed by Aydın Siyahı (4.65 mm) and lowest was recorded for Topan (3.80 mm). Whereas, among the mock-control plants the highest flesh thickness was recorded from cultivar Silindirik (9.77 mm) followed by Kemer (7.60 mm) and lowest flesh thickness was observed from Halep Karası (6.29 mm). The highest percent reduction over control was recorded for Kemer 46.06% followed by Topan 40.90% and lowest reduction was recorded for Silindirik 18.11% (Figure 2E).

Quality Traits

Total Soluble Solid (Brix value)

TSWV significantly ($p \leq 0.05$) reduced the TSS content in infected eggplant cultivars compared to mock-controls. Among the infected plants highest mean value of brix was recorded for Silindirik (5.09%) followed by Halep Karasi (4.24%) and lowest was recorded for Kemer (3.06%) and Topan (3.10%) infected cultivars. Whereas among the mock-control plants highest mean value for brix was recorded for Silindirik (6.12%) followed by Aydın Siyahı (5.51%), Halep Karası (5.45%), Kemer (5.16%) and Topan (4.91%), which is statistically similar (Figure 2-F).

Fruit Color

Fruit color of eggplant was examined for five different cultivars on infected and mock-control (non-infected) plants. The infected cultivar Topan showed light fruit skin color (51.23) in comparison to dark fruit skin color (38.91) on mock-control plants. Same results were observed for Aydın Siyahı, which showed a significantly different ($p \leq 0.05$) light color (38.29) under infected condition as compared to its mock-control (36.00). Contrarily, infected Halep Karası exhibited dark fruit color (35.11) as compared to the light color (38.95) displayed under mock-control conditions. The eggplant cultivars Kemer and Silindirik did not show significant difference ($p > 0.05$) in fruit skin color under infected and mock-control conditions (Figure 2-G).

Fruit Firmness

Fruit firmness was significantly ($p \leq 0.05$) affected by TSWV. Among the infected cultivars the lowest fruit firmness mean value was recorded from infected plants Kemer (2.77) and Topan (3.24) followed by Aydın Siyahı and Halep Karası (3.85), (4.25). Whereas for the mock-control cultivars highest mean value for fruit firmness was recorded for Silindirik (5.32) followed by Halep Karası (4.60), Topan (4.58), Aydın Siyahı (4.56), which was statistically non-significant from each other. The highest percent reduction over control was recorded for Topan 29.25% followed by Kemer 28.97% and lowest was recorded for Silindirik 4.88% (Figure 2-H).

Dry Matter Contents

Results regarding dry matter content, showed non-significant ($p > 0.05$) difference among the cultivars with the infected and uninfected mock-control plants. The cultivar Kemer showed dry matter content of 10.05% in infected one which was also statistically similar to its control (10.24%). Similarly, for the cultivar Aydın Siyahı (10.52%), Silindirik (10.27%), Halep Karası (10.36%) and Topan (10.57%) dry matter content was statistically similar to their mock-control plants (Figure 3-I).

Yield (g plant^{-1})

Yield (g plant^{-1}) was significantly ($p \leq 0.05$) affected by TSWV. Among the infected cultivars the highest yield was recorded for Silindirik (655.4 g) followed by Kemer (124.2 g) and lowest was recorded for Topan (101.7 g). Whereas from mock-control plants the lowest yield (g plant-1) was recorded from Halep Karası (364.0 g) followed by Aydın Siyahı (541.4 g) and highest was recorded from Silindirik (1316.7 g). The highest percent reduction over control was recorded for Topan and Kemer 84.22%, 83.88 followed by Aydın Siyahı 80.32% and lowest percent reduction was recorded for Silindirik 50.22% (Figure 3-J).

Correlation

The correlation study among the yield and quality variables of eggplants (Table 2) showed positive correlations between fruit length and fruit number ($r=0.84^{*}$), fruit weight and fruit length ($r=0.90^{*}$), flesh thickness with fruit weight ($r=0.97^{**}$), whereas strongly positive correlation of fruit firmness to total soluble solids ($r=-0.98^{**}$). The fruit yield was strongly correlated with fruit number ($r=-0.96^{**}$), fruit length ($r=-0.90^{**}$), fruit weight ($r=-0.97^{**}$), and flesh thickness ($r=-0.98^{**}$) of eggplant tested in this study.

Principal Component Analysis

The interrelationship among selected eggplant cultivars along with the tested variables were analysed by biplot principal component analysis (PCA) as shown in Figure 3. It revealed that the biplot for yield and quality variables PC1 and PC2 explained 91.30% variance (contributed by PC1 68.89%, and PC2 22.41%) among the eggplant cultivars for the measured traits. PCA biplot grouped the eggplant cultivars based on their response to the observed yield and quality variables. The cultivar Silindirik showed positive PC1 values. The cultivar Silindirik showed better performance for fruit firmness, fruit weight, total soluble solids, fruit yield, fruit thickness, fruit length, and fruit numbers, whereas the cultivars Kemer and Topan were sensitive. The cultivar Halep Karası and Aydın Siyahı showed average response (Figure 4).

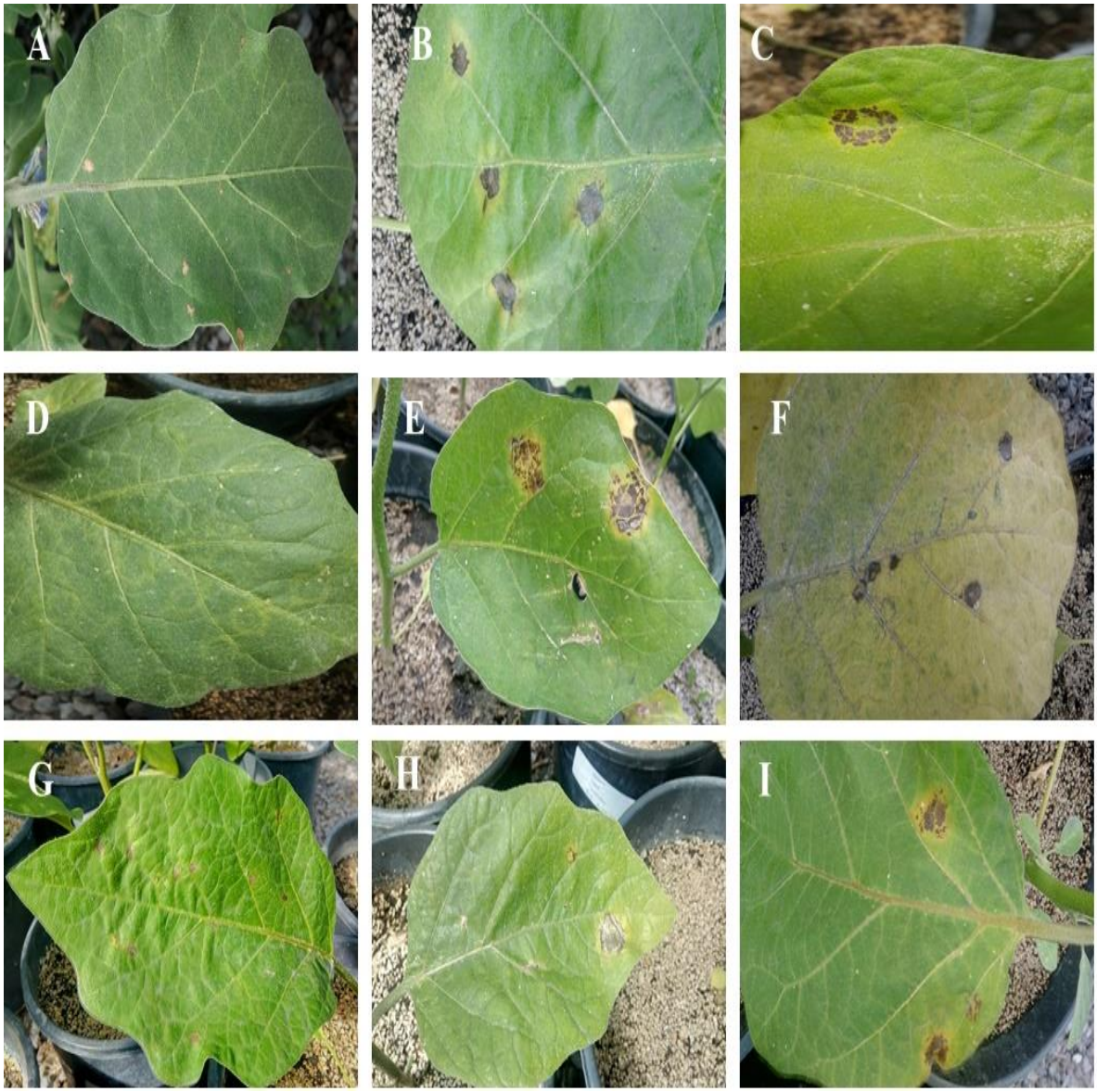
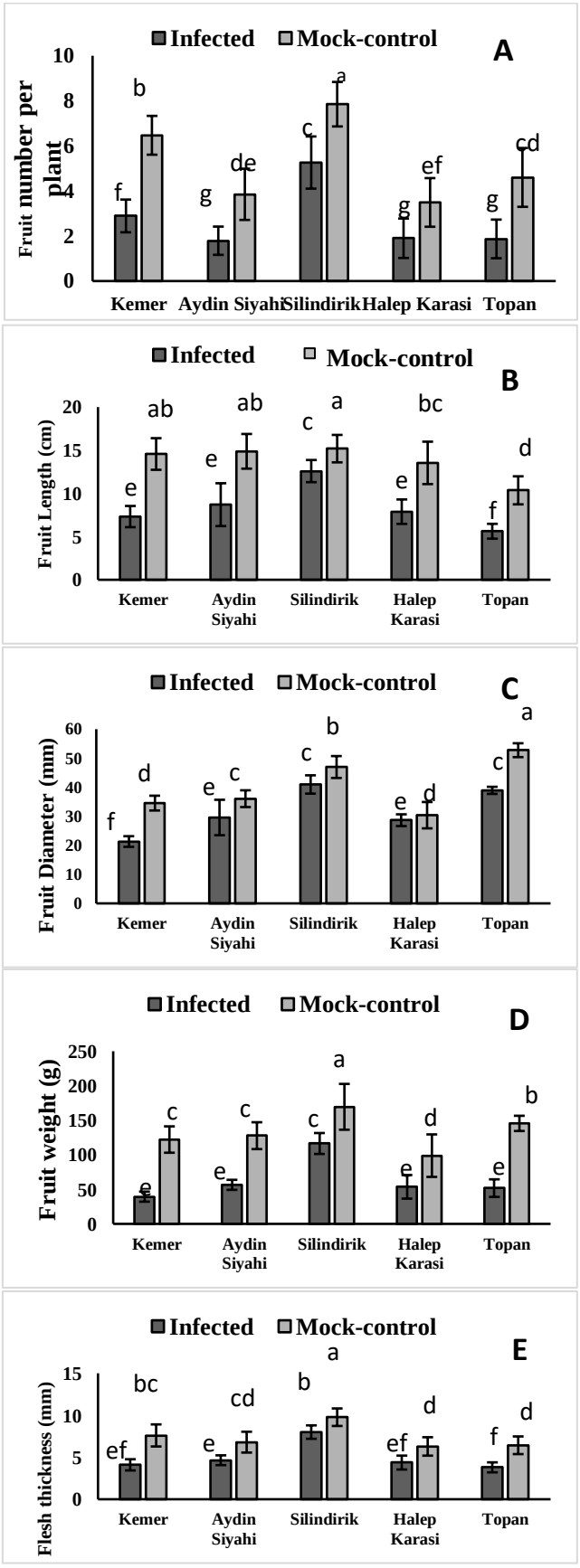


Figure 1. Tomato spotted wilt orthotospovirus (TSWV) symptoms on eggplant leaves, brown spots (A), concentric ringspot (B and G), chlorotic ringspot (D), necrosis (F) and necrotic ringspot (C, E, H, and I)


Infected
Mock-control
A
Fruit number per plant
Kemer
Aydin Siyahi
Silindirik
Halep Karasi
Topan
B
Fruit Length (cm)
C
Fruit Diameter (mm)
D
Fruit weight (g)
E
Flesh thickness (mm)

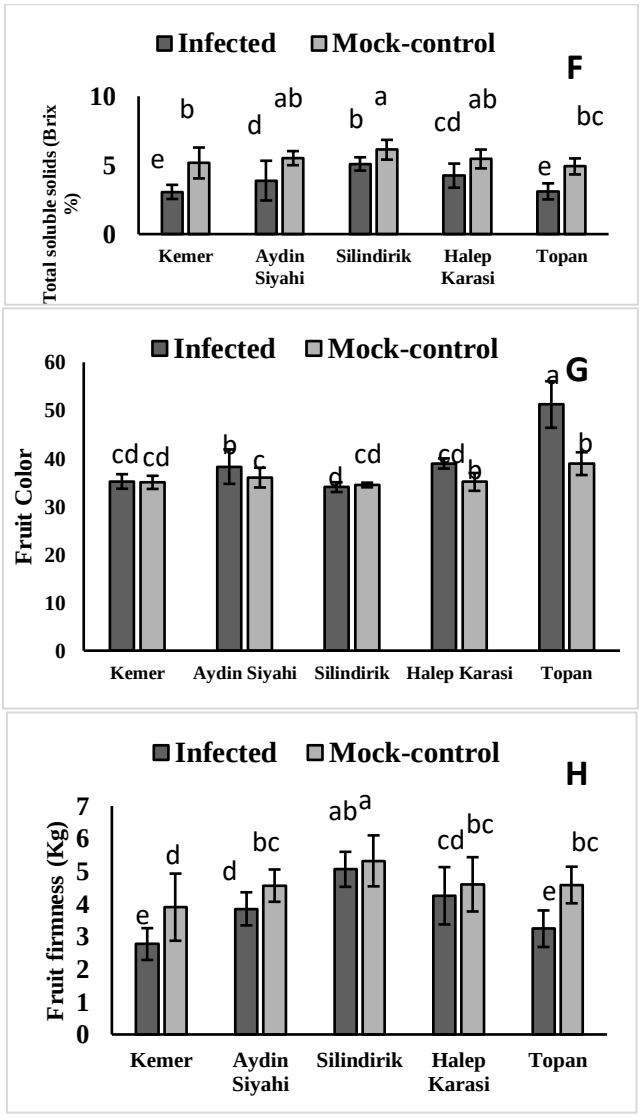


Figure 2. Fruit quality parameters of tested eggplant cultivars (both infected and mock-control plants). **A**: Number of fruits per plant, **B**: Fruit Length, **C:** Fruit Diameter. **D**: Fruit Weight, E: Fruit Thickness, **F:** Total Soluble Solids, **G**: Fruit Color, **H:** Fruit Firmness. Bar shows mean value, vertical bar represents standard deviation, alphabets sharing same letter are statistically non-significant ($p \geq 0.05$) whereas different letters show significant ($p \leq 0.05$) difference among cultivars.

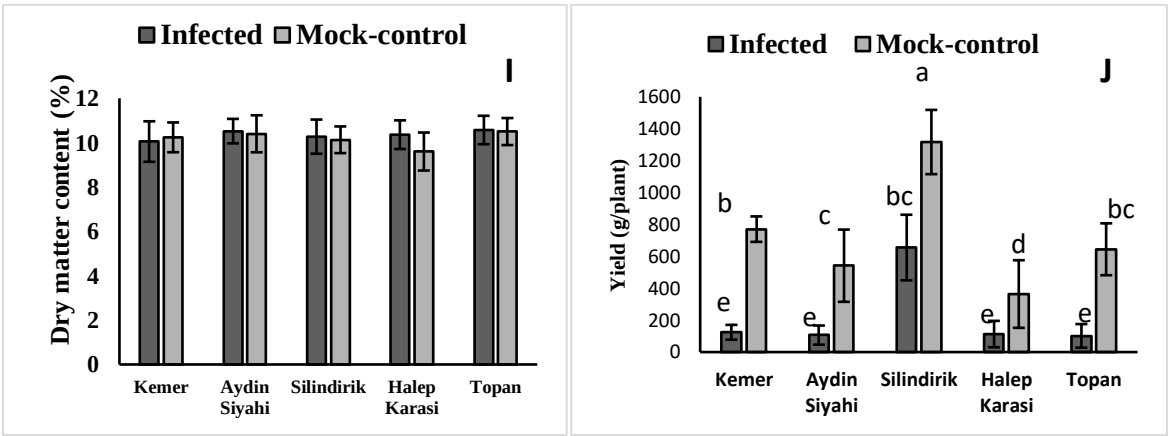


Figure 3. Fruit quality and yield parameters of tested eggplant cultivars (both infected and mock-control plants). **I:** Dry Matter Content, **J:** Yield. Bar shows mean value, vertical bar represents standard deviation, alphabets sharing same letter are statistically non-significant ($p \geq 0.05$) whereas different letters show significant ($p \leq 0.05$) difference among cultivars.

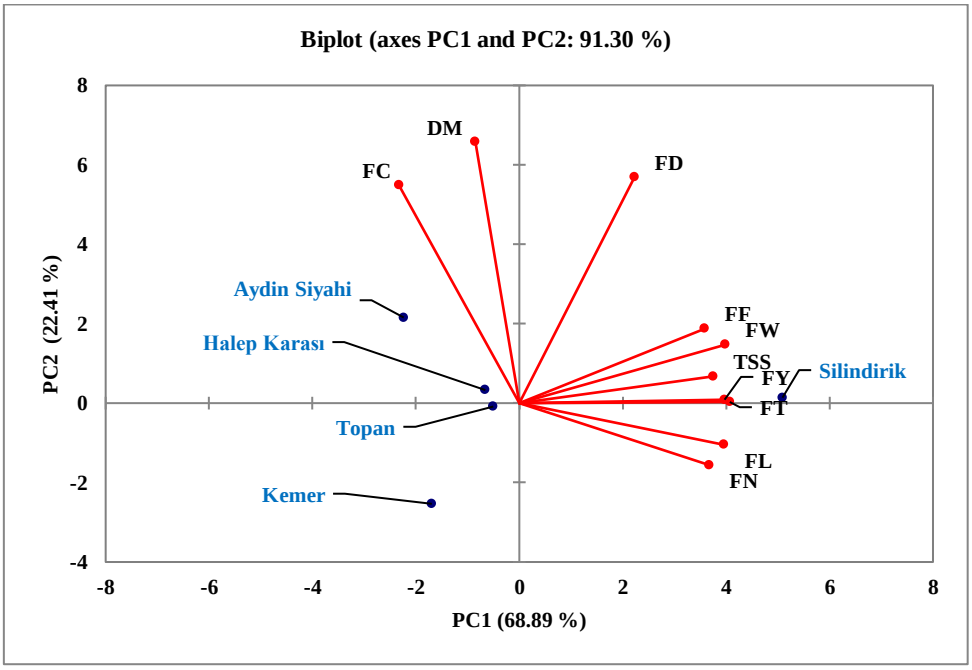


Figure 4. Principle component analysis (PCA) biplot for yield and quality variables of five eggplant cultivars infected by Tomato spotted wilt orthotospovirus (TSWV). PCA biplot is a combination of score plot of eggplant cultivars (represented in blue text) and loading plot of variables (represented by red vectors; black text). FD: fruit diameter, FF: fruit firmness, FW: fruit weight, TSS: total soluble solids, FY: fruit yield, FT: fruit thickness, FL: fruit length, FN: fruit numbers, DM: dry matter contents, FC: fruit color.

Table 1. Details of ELISA positive results and infection rate in eggplant cultivars.

Cultivars	Number of inoculated plants	Total number of tested samples	Number of TSWV infected samples	Infection rate
Kemer	25	17	10	58%
Aydın Siyahı	25	19	9	47%
Halep Karası	25	18	8	44%
Topan	25	19	10	52%
Silindirik	25	18	7	38%

Table 2. Pearson's correlation coefficients between the yield and quality traits of eggplant with the inoculation of Tomato spotted wilt orthotospovirus (TSWV)

	FN	FL	FD	FW	FT	TSS	FC	FF	DM	FY
FN	1	0.847*	0.421	0.866*	0.92*	0.659	-0.569	0.586	-0.493	0.961**
FL		1	0.369	0.904*	0.96**	0.905*	-0.719	0.840*	-0.268	0.903*
FD			1	0.718	0.56	0.476	0.376	0.587	0.532	0.604
FW				1	0.97**	0.871*	-0.374	0.866*	-0.035	0.970**
FT					1	0.873*	-0.550	0.833*	-0.209	0.983**
TSS						1	-0.536	0.985**	-0.026	0.799
FC							1	-0.384	0.717	-0.474
FF								1	0.131	0.762
DM									1	-0.259
FY										1

** Highly significant ($p<0.01$), *significant ($p<0.05$). FN, fruit number, FL, fruit length, FD, fruit diameter, FW, fruit weight, FT, flesh thickness, TSS, total soluble solids, FC, fruit color, FF, fruit firmness, DM, dry matter, FY, fruit yield.

Discussion

Current study showed characteristic symptoms of virus including ringspots and necrosis that started to appear 10 to 14 days after inoculation (Figure 1). Similar TSWV symptoms including ringspot, leaf yellowing and necrotic spots in tomato plants after 14 days of inoculation were reported earlier and that disease severity varied among the different cultivars (Ramkat et al., 2006). In eggplant, symptoms such as deformed leaves, necrosis of leaves, molted and stunted plants with the inoculation of TSWV have been observed (Kamberoglu et al., 2009). The infection rate of TSWV in this study was highest in cultivar Kemer (58%) followed by Topan (52%), whereas lowest infection rate was observed in Silindirik (38%), which performed best performance against TSWV compared to all tested cultivars (Table 1). Similar infection level ranging from 41% to 68% with similar symptoms was reported in different cultivars of tomato (Farooq and Akanda, 2007). The fruit number was significantly affected by TSWV in infected eggplants compared to mock-controls (Figure 2-A). The reduction percentage in number of fruits per plant ranged from 32.9 to 59.3% in all eggplant cultivars. Our results regarding reduction in fruit number were consistent with the findings that TSWV in tomato crop also had a significant effect on reduction of fruit number ranging from 50 to 72% (Farooq and Akanda, 2007). In another study the similar results in fruit number was reported by TSWV with a reduction of 20.18% in fruit numbers in pepper plant (Sevik and Sokmen, 2012). Furthermore, the results of this study were consistent with an earlier report of 90% decrease in fruit number of tomato crop by TSWV (Ramkat et al., 2006). The fruit length of mock-control plants was significantly higher than the infected plants (Figure 2-B). The reduction percentage of fruit length was 17.1 to 49.7% in all the eggplant cultivars. Our results are in accordance with the findings in which it was reported that impact of TSWV on reduction of fruit length was from 11 to 68% (Farooq and Akanda, 2007). Similar decrease in fruit length of tomato crop by 11.9% with the inoculation of TSWV was also reported by (Sevik and Sokmen, 2016). These studies showed that the infection of TSWV could reduce the fruit length.

In the current study the fruit diameter was also significantly affected by TSWV infection causing a reduction of 12.8 to 38.3% (Figure 2-C), which is in accordance with the findings of a reduction of 10.9% fruit diameter in tomato plant (Sevik and Sokmen, 2012). Fruit weight was significantly affected by TSWV resulting in reduction of 31.3 to 67.7% (Figure 2-D). The highest fruit weight of 169.4 g was measured from Silindirik mock-control plants whereas, Kemer infected by TSWV resulted in lowest fruit weight 39.4 g. The response of cultivars was different regarding fresh weight reduction against TSWV that might be due to their tolerance level. Viral diseases reduce yield, TSWV disease is being one of them (Ramkat et al., 2006). Significant decrease in fruit weight was reported ranging from 27% to 60% depending on the response of varieties to TSWV infection. In another study, it was revealed that TSWV affected the fresh fruit weight as well as plant weight (Díaz-Pérez et al., 2007). Kim et al. (2004) reported that TSWV caused weight and quality loss in pepper.

TSWV had a significant effect on fruit flesh thickness in the current study causing a reduction of 18.1 to 46.0% (Figure 2-E). The reduction rate varies among the cultivars due to several factors. For example, fruit size and shape also could be a reason for difference in flesh thickness. Several studies reported that TSWV had effect on fruit size, length and diameter; it might well be the decisive factor for reduction in flesh thickness. Based on the results, it was found that the infection of TSWV had reduced the total soluble solid (Brix) of fruit. The reduction rate was in the range of 16.8 to 40.6 percent among the cultivars (Figure 2-F). It might be due to reduction in water supply, decreased photosynthetic rate or poor assimilation of nutrient contents in infected plants. Our results are also similar to the results of a study that reported the decrease of soluble solids content in pepino by *Tomato mosaic virus* (Perez-Benlloch et al., 2001).

The results of current study indicated that TSWV influenced fruit color of eggplant as well. The changes in fruit color could also be due to different cultivars tested in the study. Nevertheless, in severely infected cultivars, the difference in fruit color was significantly different from their mock-control plants (Figure 2-G). The fruits from the infected plants indicated lighter color compared to healthy fruits. Similar results were obtained for color response in tomato against TSWV (Farooq and Akanda, 2007). Our results are also comparable to the study of that reported for the color variation of fruits due to TSWV infection (Swift, 2006). Fruit firmness traits attributes describes fruit texture and are vital in determining final fruit quality. In the current study, TSWV has influence on fruit firmness in a highly significant way (Figure 2-H). The firmness of vegetables is affected by different traits such as biochemical constituents, cellular organelles, cell wall composition and water content or turgor. Thus, TSWV affecting any of these traits could change the fruit firmness and could lead to changes in fruit quality. Examination of the dry matter content of eggplant fruits in the infected and mock-control plants demonstrated that the differences between the cultivars were not statistically significant (Figure 3-I). Dry matter content could be influenced by different parameters. However, it is reported that *Tobacco mosaic virus* infection has no effect on dry matter content (Elegba et al., 2013).

Eggplant yield is mostly associated with healthy vegetative growth of plants throughout the growing season. Results of this study revealed that TSWV damaged the plant growth which resulted in lower yield traits. Results indicated that the eggplant cultivars had different tolerance level as percent reduction in yield varies among the cultivars. Most

infected cultivar was Topan with highest percent fruit yield reduction of 84.2% while, the lowest infected one was Silindirik with 50.2% fruit yield reduction (Figure 3-J). These results were in agreement with the study of Ramkat et al., 2006 that reported the fruit yield loss of 37-90% due to TSWV in different tomato varieties. Farooq et al., 2017 found that under different tolerant conditions, TSWV resulted in 44.1- 55.6% reduction in fruit yield. Similarly, researchers determined that prior to harvesting TSWV reduced the crop yield by 2.1% to 2.3% for each day (Pérez-Benlloch et al., 2001). Previous reports showed that viruses caused different diseases in *Solanaceae* family, among them the effect of TSWV on yield varied with variety and stage of inoculation. Rapando et al., (2009) also found that TSWV disease caused 57% and 32% crop yield reduction in two different cultivars of tomato. Most of the fruits formed on the infected plants by TSWV exhibited abnormal coloration and the marketable yield of tomatoes was drastically reduced due to the abnormal ripening (Moriones et al., 1998).

Conclusion

Current study was conducted to evaluate the performance of five common eggplant cultivars with the infection of TSWV. Our results revealed a differential response of eggplant cultivars. It was concluded that cultivar Kemer showed the highest infection rate followed by the cultivar Topan and Aydın Siyahı. Infection of TSWV significantly reduced the yield and quality traits of eggplant such as fruit number, fruit length, fruit diameter, fruit weight, flesh thickness, total soluble solid, fruit color, fruit firmness and yield in infected plants as compared to their respective mock-control plants. The results showed that among the five cultivars, the performance of Kemer and Topan was poor, which suggested that these cultivars are highly sensitive to TSWV. Whereas, the performance Silindirik was good, this suggested that this cultivar might be tolerant to TSWV. Information presented here illustrated that TSWV had devastating effects on quality and yield parameters of eggplants. Therefore, strategies to prevent TSWV infection and control measures to avoid crop losses should be implemented. This study will help plant breeders to understand potential effects of TSWV on eggplant cultivars. Results of the study may also help breeders with the development of sustainable TSWV resistant varieties by using these tolerant cultivars to cope with TSWV infections in the field.

Compliance with Ethical Standards

Conflict of interest

The author declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Not applicable.

Funding

No financial support was received for this study.

Data availability

Not applicable.

Consent for publication

Not applicable.

Acknowledgement

This article is produced by Master's thesis of Afzal Alam. The authors thank to Mr. Ali Ferhan Morca (T.R. Ministry of Agriculture and Forestry, Ankara Directorate of Agricultural Quarantine) for providing the isolate of TSWV and also to Qurat-ul Ain SAJID and Nida ÜNLÜ (Ph.D. students) for their helps during the experiments.

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