Original Article
DOI: https://doi.org/10.70749/ijbr.v3i10.2529

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://ijbr.com.pk
ISSN: 2960-2793/ 2960-2807

Evaluation of Different Plant Powder Formulations against Fusarium Wilt in Tomato

Faizan[1], Fazli Raziq[1], Saeed Ullah[1], Ali Muhammad[2], Muhammad Naseer Khan[1], Dost Mohammad[3], Aqib Nouman[4], Zahid Hussain[3], Muhammad Yasin[1], Bilal Ahmad[5], Taimur Iqbal[1]

[1]Department of Plant Pathology, Faculty of Crop Protection Sciences, The University of Agriculture, Peshawar, Pakistan
[2]Directorate of Non-Timber Forest Products, Merged Areas, Peshawar, Pakistan
[3]Department of Plant Protection, Faculty of Crop Protection Sciences, The University of Agriculture, Peshawar, Pakistan
[4]District Officer, Soil and Water Conservation, Hangu, Pakistan
[5]Cereal Crops Research Institute, Pirsabak, Nowshera, Pakistan

ARTICLE INFO

Keywords: Tomato, Fusarium wilt, Plant powders, Disease management, Biological control.

Correspondence to: Faizan,
Department of Plant Pathology, Faculty of Crop Protection Sciences, The University of Agriculture Peshawar, Pakistan·
Email: faiz125@aup.edu.pk

Declaration
Authors' Contribution: Mentioned at the end of the paper.

Conflict of Interest: No conflict of interest.

Funding: No funding received by the authors.

Article History
Received: 24-08-2025 Revised: 15-10-2025
Accepted: 21-10-2025 Published: 30-10-2025

ABSTRACT

Background: Fusarium wilt is a dangerous disease that lowers tomato quality and productivity. It is especially harmful in sandy, acidic soils found in temperate regions. Methods of chemical control can be expensive and environmentally damaging. An efficient, safe, and natural method of managing this illness is to use plant powders. **Objective:** To evaluate the effectiveness of different plant powder formulations in controlling Fusarium wilt in tomato plants. **Methodology:** In current study, three weeds powder viz. Hopbush plant (*Dodonaea viscosa*), Sun spurge (*Euphorbia helioscopia*) and Papra (*Fumaria indica)* were evaluated for the control of *Fusarium oxysporum* f.sp. *lycopersici*, the cause of tomato wilt disease, on Potato Dextrose Agar (PDA) medium in lab and *in planta*. In the *in vitro* experiment, from each plant, three different concentrations (4, 8 and 16g/L PDA medium) were used to study their inhibitory effect on the colony diameter of the *Fusarium*. **Results.** All three tested plant powders significantly (P=0.00) reduced the colony diameter of pathogen (*Fusarium oxysporum)* compared to control. *F. indica* showed the greatest inhibition, recording the lowest colony diameter of 2.1 cm and 2.2 cm at 16 g L^{-1} after one and two weeks of incubation at 25 °C. In the screen house trial, applying 40 g kg^{-1} soil of *F. indica*, *D. viscosa*, and *E. helioscopia* reduced disease severity to 33.20%, 46.60%, and 52.60%, respectively, compared with 84% in the control. The area under the disease progress curve (AUDPC) was significantly lower (P=0.00) in all treated plants than in untreated ones. *F. indica* also showed superior effects on plant height, fresh biomass, fruit number, fruit weight, and fruit size compared to other treatments. **Conclusions:** It was concluded that *F. indica* at 40g kg^{-1} soil can be used for effective control of Fusarium wilt of tomato.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetables (Pritesh *et al.,* 2011) with its global annual production of 182 million metric tons, half of which are used for processing. Five largest tomato producing countries are China, USA, India, Turkey and Brazil, providing 75% of the global production annually (Gatah,2017). In Pakistan, tomato has a significant economic value, cultivated on an area of 63.2 thousand hectares with a total production of 570.6 thousand tones, @ 9.02 tons ha^{-1}. Khyber Pakhtunkhwa province tomato is cultivated on 13.1 thousand hectares, giving tomato production of 132 thousand tons @ 9.9 thousand tons ha^{-1} (GoP, 2018).

Consumption of tomatoes is increasing due to population increase, and it is available at low prices compared with other vegetables with high nutritive values. It is used as sauces, salad, fresh form and cooked form. It is available throughout the year in many different regions in the world (Chohan *et al.,* 2008). America and Europe are the two main sources of commercially sown cultivars that are introduced to Pakistan (Noonari *et al.,* 2015). It contains an antioxidant called lycopene, which protects humans against cancer (Benton, 1999). 30 °C and above temperature inhibits lycopene formation, while fruit formation delays by low temperature (Brandt *et al*., 2006: Hanson *et al.*, 2001).

Tomato production drastically decreases due to many problems including fungal diseases. Fusarium wilt is an extremely severe disease in Khyber Pakhtunkhwa. *F.oxysporum* f. sp. *lycopersici* the cause of tomato wilt disease, is a soilborne plant pathogen in the family Nectriaceae first described by G.E. Massee in England in 1985 (Rekah *et al.,* 2000). Previously the disease has been

reported for more than 30 countries in the world. In warm climate the disease is more severe (Kuc, 1982). The disease previously destroyed tomato fruit production in South-Eastern states of United States of America and in some parts of Florida. However, the use and development of resistant cultivars have been helpful in reducing the damage and losses caused by Fusarium wilt of tomato (Srobar, 1978).

Different Fusarium species cause losses in tomato production (Wang *et al.,* 2011), among them associated with wilt disease are *Fusarium verticilloides, F. oxysporum*, and *F. graminearum* (Rozlianah and Sariah, 2010). They infect tomato plants through their crown area and roots at any growth stage. *F. oxysporum*, block vascular tissues, caused infected plants showed premature wilting due to stress (Gupta *et al.* 2000, Adisa *et al.,* 2018). The disease is more severe in sandy soil, and the pathogen can survive in the soil for long time. However, soil temperatures above 35°C or low 15 °C) delays wilt development (Di Pietro *et al.,* 2003).

Fumaria is a common weed with worldwide distribution having antifungal properties. The genus Fumaria consists of 45 species commonly known as "beggary, earth smoke, fumitory and wax dolls" (Orhan *et al.,* 2010). *F. indica* is a small, annual herb commonly known as "Papra" and "Shahtrah" in Pakistan (Chopra *et al.,* 2002) and "common fumitory" in English. *F. indica* is a common winter annual weed in Pakistan, India, Persia, Mongolia and Afghanistan (Kirtikar *et al.,* 1985). Similarly, *Euphorbia helioscopia*, a common weed from Euphorbiaceae, commonly known as sun spurge, is proven as an antifungal and antibacterial (Vijaya *et al*., 1995; Vijaya and Ananthan, 1997), medicinal and larvicidal (Lanhers *et al.,* 1990; 1991). Antifungal activity of *E. helioscopia* ethanolic extract of leaves against *Aspergillus niger* and *A. flavus* is proven (Geeta and Padma, 2011). Likewise, hopbush (*Dodonaea viscosa* L.) a shrub from Sapindaceae is widespread in Pakistan (Rajeswari *et al.*, 2011). Used for the treatment of diarrhea, skin infections, stomach aches, rheumatism and sour throats, hemorrhoids and as an antipruitic (Getie *et al*., 2003). It inhibited the mycelial growth of *Rhizoctonia solani* by 57.91% and *Alternaria solani* by 51.87% (Rajeswari*et al.*, 2011). All these plants having antifungal properties are available easily and in abundance. Therefore, the present experiment is arranged to evaluate their efficacy for the control of Fusarium wilt of tomato.

MATERIALS AND METHODS

Source of Pathogen: *Fusarium oxysporum* f.sp. *lycopersici (*FOL) culture was obtained from the Department of plant pathology and maintained it in refrigerator at 4^0C. FOL was grown on potato dextrose agar (PDA) in sterilized conditions, labeled and incubated at 27°C for 1-2 weeks for sub-culturing. Similarly, *Euphorbia helioscopia*, *Fumaria indica* and *Dodonaea viscosa* were collected from Malakandher farm Peshawar and identified by Dr. Bakhtiar Gul, Associate Prof. Department of Weed Science. Plants were thoroughly washed with tap water and shade dried, crushed into fine powders.

***In vitro* assay:** The poisoned food method was used to check the efficacy of dried powders on the *in-vitro* growth of FOL. Different concentrations (4, 8 & 16g L^{-1}) were prepared and added to PDA after cooling down to 50°C along a control (PDA medium without extract application). The pathogen was inoculated at the center of each petri dish, and the dishes were wrapped and labeled aseptically and incubated at 27°C for two weeks. After fungal growth, the inhibitory effect was assessed by measuring the colony diameter with a transparent ruler along two perpendicular lines. CR design was used, and each treatment was replicated five times. The reduction in growth of *F.oxysporum* f. sp. *lycopersici* in different treatments was calculated by using the formula:

$$\% \text{ Growth reduction} = \frac{(\text{Growth in control medium} - \text{Growth in amended medium})}{\text{Growth in control medium}} \times 100$$

Tomato nursery raising: Seeds of a commercially popular tomato cultivar Rio-grande were planted in prepared nursery bed using standard cultural practices. Thirty days old seedlings were transplanted to pots filled with clay, sand and FYM in a ratio of 1:1:1.

***In vivo* experiment:** The experiment was conducted under screen house conditions. Each pot was filled with 1 kg pasteurized soil, and each treatment was replicated five times. One seedling was transplanted to each pot having 15 cm diameter. Two doses (20g kg^{-1} and 40g kg^{-1}) of the dried powder of the weeds were thoroughly mixed in the pots containing pasteurized soil just before transplanting. Each pot was moistened and inoculated with 10 ml of the pathogen suspension (10^4 conidia ml^{-1}) just after mixing of the dried powder with the soil in each pot. Data was taken on disease severity, plant height, number of fruits, fruit size, fruit weight and fresh biomass. Severity ratings for FOL inoculated plants were noted using a scale of 0-4 as described by Song *et al*., (2004).

0	No symptoms
1	A light infection, 2-3 leaves become yellow.
2	Moderate infection, 3-5 leaves become yellow, 50% of the leaves become wilted.
3	Severe infection, 75% of the leaves become wilted and growth is retarded.
4	Complete infection, almost all leaves become wilted and the plant died.

Area under disease progress curve (AUDPC) was calculated from the fortnightly recorded disease severity data under three times of observations according to the following formula as described by Madden *et al.,* (2007).

$$\textbf{AUDPC} = \sum_{i=0}^{n} \left(\frac{X_{i+1} + X_i}{2}\right)(T_{i+1} - T_i)$$

Where: n = Total number of observations
Ti = Time of ith observation
Xi = Quantity of infection at ith observation
X_{i+1} = Quantity of infection at 2nd observation
T_{i+1} = Time of 2nd observation

Treatments Details for Lab Experiment

T1 = *D. viscosa* (4g L^{-1}) T2 = *D. viscosa* (8g L^{-1}) T3 = *D. viscosa* (16g L^{-1})
T4= *E. helioscopia* (4g L^{-1}) T5= *E. helioscopia* (8g L^{-1}) T6 = *E. helioscopia* (16g L^{-1})
T7 = *F. indica* (4g L^{-1}) T8 = *F. indica* (8g L^{-1})
T9 = *F. indica* (16g L^{-1})
T10 = Control

Treatments Details for Screen House Experiment

T1 = *D. viscosa* (20g kg^{-1} soil) T2 = *D. viscosa* (40gkg^{-1} soil)

T3= *E. helioscopia* (20g kg^{-1} soil) T4 = *E. helioscopia* (40g kg^{-1} soil)
T5 = *F. indica* (20g kg^{-1} soil) T6 = *F.indica* (40g kg^{-1} soil)
T7 = Healthy control T8 = Inoculated control

Figure 1
Pure Culture of FOL (a) Macro Conidia and (b) Micro Conidia of FOL

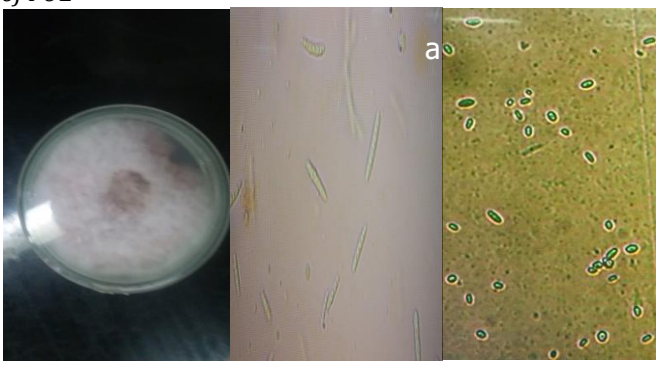
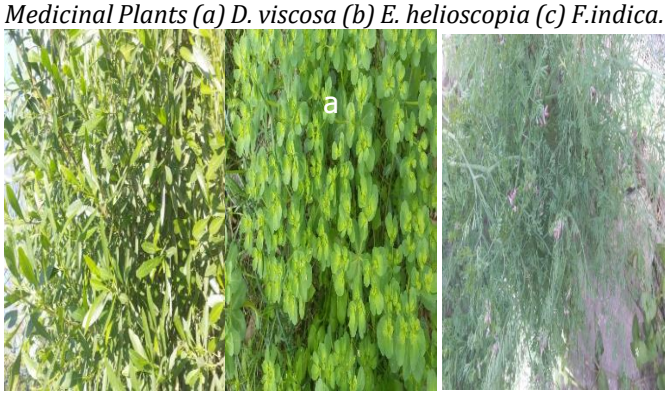


Figure 2
Medicinal Plants (a) D. viscosa (b) E. helioscopia (c) F.indica.



STATISTICAL ANALYSIS

The data recorded on different parameters were subjected to ANOVA technique using statistical package STATISTIX 8.1. Least significant differences (LSD) test was used for means separation where ANOVA was significant.

RESULTS

Reduction in Colony Diameter of *fusarium oxysporum*f.sp. *Lycopersici* (fol) on Potato Dextrose Agar (pda) Medium.

Highly significant (P=0.00) differences were recorded among the treatments (Figure 3, 4 and 5). All the 3 plants reduced the pathogen growth significantly even at the lowest dose of 4g/L (Tables 1 and 2). Colony diameter of the FOL ranged from 2.2-8.2 cm (Table 2). The lowest reduction in growth of the pathogen was observed on PDA medium amended with the powder of *F. indica* @ 16g/L (2.2 cm) followed by 8g/L of *F. indica* (2.7 cm) and 16g/L *D. viscosa* (2.9 cm) after 2 weeks of incubation at 25°C. Reduction (%) over control in treatments were significant (P = 0.00). The highest reduction in growth of the FOL was observed on PDA medium amended with the powder of *F. indica* @ 16g/L (73.17%) followed by 8g/L of the same plant (67.07%) and 16g/L *D. viscosa* (64.63%) after two weeks of incubation at 25°C. In the control plates the highest colony diameter of the FOL was observed (8.2 cm).

Figure 3 *Effect of D. viscosa on the growth of the pathogen. Clockwise from top left growth of the pathogen on PDA containing no powder; growth of the pathogen on PDA containing powder@4g/L; pathogen growth on PDA containing powder @ 8g/L; pathogen growth on PDA with powder @ 16g/L.*

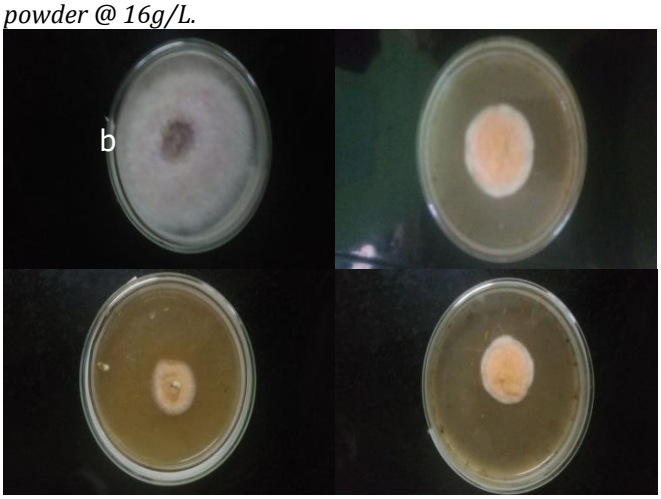


Figure 4 Effect of *E. helioscopia* on the radial growth of pathogen. L-R growth of pathogen on control/ no powder; growth of the pathogen on PDA with powder @ 4g/L; growth of the pathogen on PDA with powder @ 8g/L; growth of the pathogen on PDA with powder @ 16g/L.

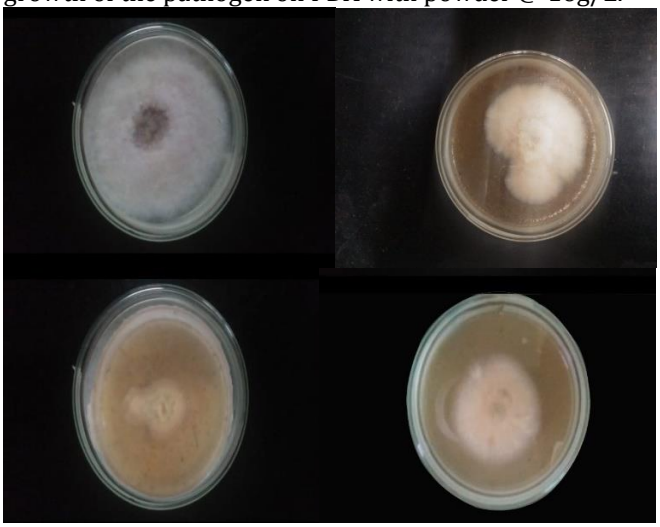


Table 1
Effect of Different Plant Powders on Colony Diameter of FOL Grown on Potato Dextrose Agar (PDA) Medium Incubated at 27°C for a Week.

Treatments	Colony diameter (cm)	% reduction in growth
Dodonaea viscosa 4g/L medium	3.3 d	56.00
D. viscosa 8g/L medium	2.9 e	61.33
D. viscosa 16g/L medium	2.7 fg	64.00
Euphorbia helioscopia 4g/L medium	4.4 b	41.33
E. helioscopia 8g/L medium	3.9 c	48.00
E. helioscopia 16g/L medium	3.4 d	54.66
Fumaria indica 4g/L medium	2.8 ef	62.66
F. indica 8g/L medium	2.5 g	66.66
F.indica 16g/L medium	2.1 h	72.00
Untreated control	7.5 a	_

$LSD_{(0.05)}$ = 0.16 Means followed by different alphabets in column are statistically differ (P ≤ 0.05)

Figure 5 *Effect of F. indica on the radial growth of pathogen. Clockwise from top left pathogen growth on control PDA/ no powder; pathogen growth on PDA with powder @ 4g/L; growth of the pathogen on PDA amended with the powder @ 8g/L; growth of the pathogen on PDA with the powder @ 16g/L.*

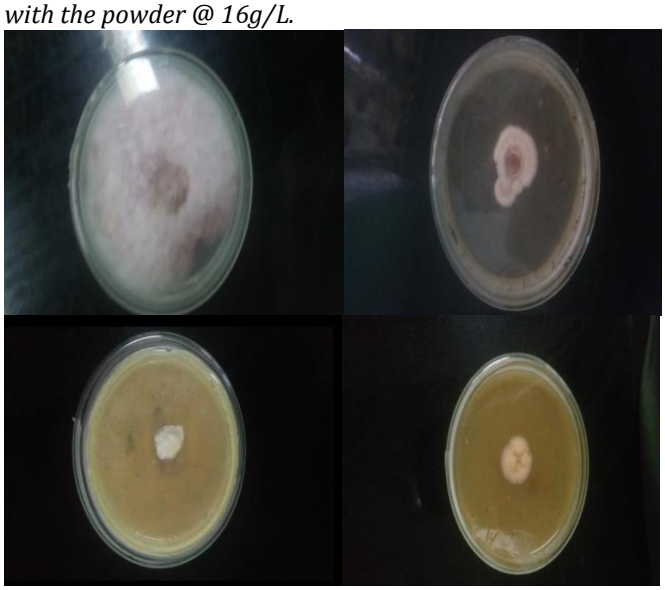


Table 2

Effect of Different Plant Powders on Colony Diameter of FOL Grown on PDA Medium after Two Weeks Incubated at 27°C.

Treatments	Colony diameter (cm)	% reduction in growth
Dodonaea viscosa 4g/L medium	3.5 d	57.31
D.viscosa 8g/L medium	3.1 e	62.19
D.viscosa 16g/L medium	2.9f	64.63
Euphorbia helioscopia 4g/L medium	4.7 b	42.68
E.helioscopia 8g/L medium	4.1 c	50.00
E.helioscopia 16g/L medium	3.6 d	56.09
Fumaria indica 4g/L medium	3.1 e	62.19
F. indica 8g/L medium	2.7 f	67.07
F.indica 16g/L medium	2.2 g	73.17
Untreated control	8.2 a	—

$LSD_{(0.05)} = 0.17$ Means sharing different letters in column are statistically different ($P \leq 0.05$)

Screen House Experiment

Effect of different plant powders on disease severity (%): Significant differences were recorded between the treatments (Figure 6, 7 and 8). After 15 days of inoculation, disease severity data were taken. The maximum disease severity (36%) was observed in untreated inoculated control while the lowest disease severity (0%) was observed in health control. Among the plants used, the lowest disease severity was recorded in the plants treated with the high dose (40g/kg soil) of *F. indica* followed by same dose of *D. viscosa* (18.60%) and the high dose (40g/kg soil) of *E. helioscopia* (24.60%) (Figure 6). After 30 days of inoculation a similar trend was observed when data were recorded. Among the medicinal plants, the lowest disease severity (20.80%) was recorded in plants treated with the high dose (40g/kg soil) of *F. indica* followed by the high dose of *D.viscosa* (28.6%) (Figure 7). After 45 days of inoculation, disease severity data were different significantly among the treatments. The high dose of *F.indica* powder treated pots showed disease severity of 33.20% followed by the high dose of *D. viscosa* powder 46.60% and the high dose of *E. helioscopia* (52.60%) respectively (Figure 8). while the maximum disease severity (84%) was observed in the untreated inoculated control plants and the lowest (0%) in the health control.

Figure 6

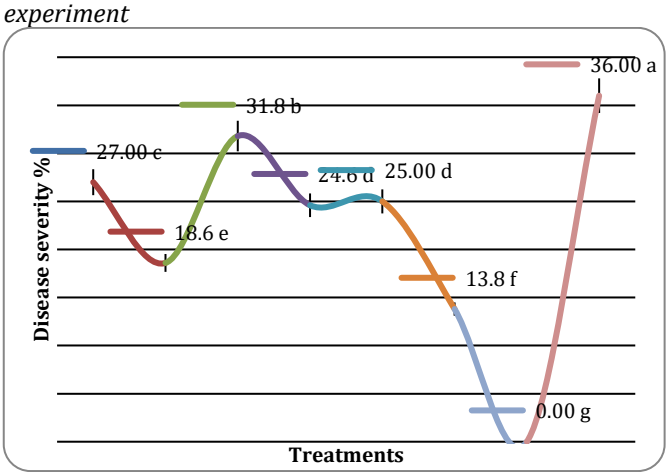
Symptoms of Fusarium wilt of tomato (a) Yellowing of leaves and (b) Wilting

Effect of different Plant Powders on Area Under Disease Progress Curve (AUDPC) of Fusarium Wilt of Tomato

The % disease severity was observed fortnightly three times after inoculation and AUDPC values were calculated for the different treatments. Significant (P = 0.00) differences were observed among the treatments (Figure 9 and Table 3). In the untreated inoculated control plants, the maximum AUDPC value (670.80) was recorded while the minimum value of 0 was observed in the healthy control (Figure 9(d). Among the medicinal plants, the minimum AUDPC value (170.33) was observed in plants treated with the high dose (40g/kg soil) of *F. indica* (Figure 9(c) followed by the high dose of *D. viscosa* (326.53) (Figure 9(a) and the high dose of *E. helioscopia*(389.40) (Figure 9(b).Overall, dried powder of *F.indica* was the most effective and that of*E.helioscopia* was the least effective in reducing AUDPC of tomato plants.

Figure 7

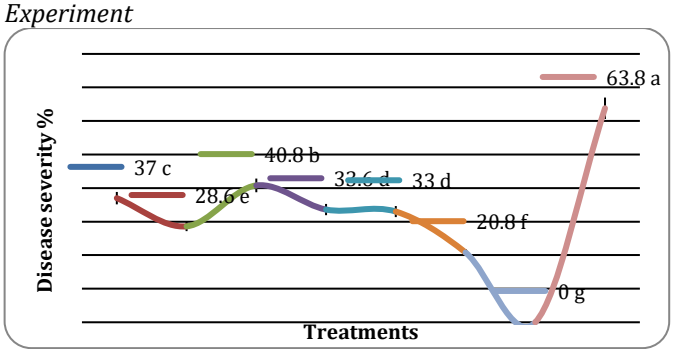
Effect of different treatments on disease severity (%) observed after 15 days of inoculation in screen house experiment



T1 = *Dodonaea viscosa* (20g/kg soil) T2 = *D. viscosa* (40g/kg soil)
T3= *Euphorbia helioscopia* (20g/kg soil) T4 = *E. helioscopia* (40g/kg soil)
T5 = *Fumaria indica* (20g/kg soil) T6 = *F.indica* (40g/kg soil)
T7 = Healthy control T8 = Inoculated control

Figure 8

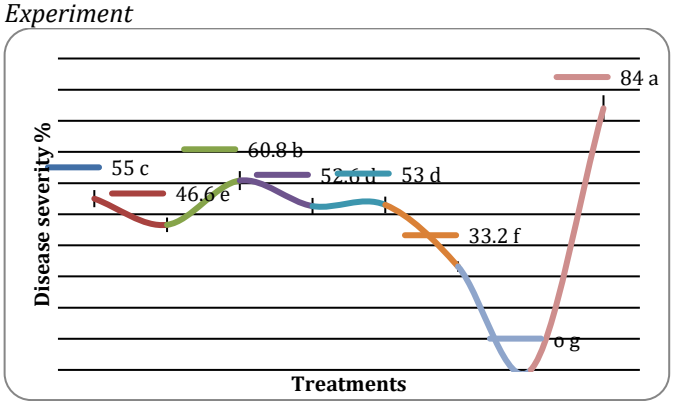
Effect of different Treatments on Disease Severity (%) Observed after 30 Days of Inoculation in Screen House Experiment



T1 = *Dodonaea viscosa* (20g/kg soil) T2 = *D. viscosa* (40g/kg soil)
T3= *Euphorbia helioscopia* (20g/kg soil) T4 = *E. helioscopia* (40g/kg soil)
T5 = *Fumaria indica* (20g/kg soil) T6 = *F.indica* (40g/kg soil)
T7 = Healthy control T8 = Inoculated control

Figure 9

Effect of different Treatments on Disease Severity (%) Observed after 45 Days of Inoculation in Screen House Experiment



T1 = *Dodonaea viscosa* (20g/kg soil) T2 = *D. viscosa* (40g/kg soil)
T3= *Euphorbia helioscopia* (20g/kg soil) T4 = *E. helioscopia* (40g/kg soil)
T5 = *Fumaria indica* (20g/kg soil) T6 = *F.indica* (40g/kg soil)
T7 = Healthy control T8 = Inoculated control

Figure 9(a)

Effect of different Treatments of D. viscosa on Area Under Disease Progress Curve (AUDPC) of Fusarium wilt of Tomato when Observed Fortnightly Intervals for 45 Days

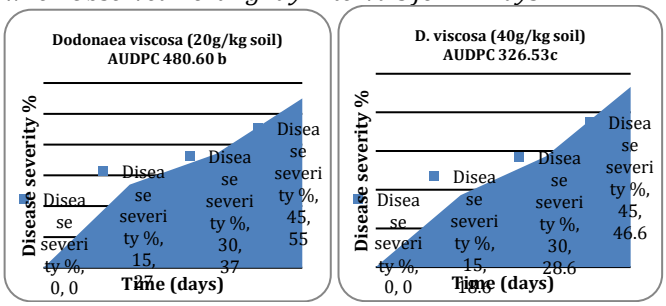


Figure 9(b)

Effect of different Treatments of E. helioscopiaon AUDPC of Fusarium wilt of Tomato when Observed Fortnightly Intervals for 45 Days

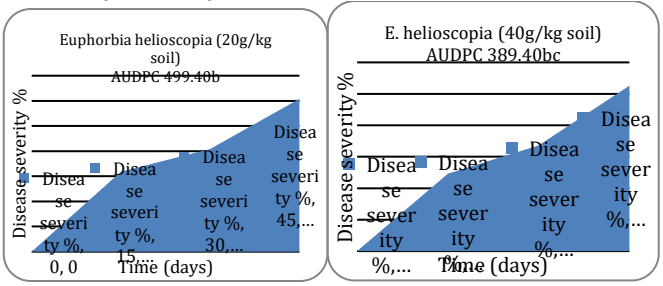


Figure 9(c)

Effect of different Treatments of F. Indicaon AUDPC of Fusarium wilt of Tomato when Observed Fortnightly Intervals for 45 Days

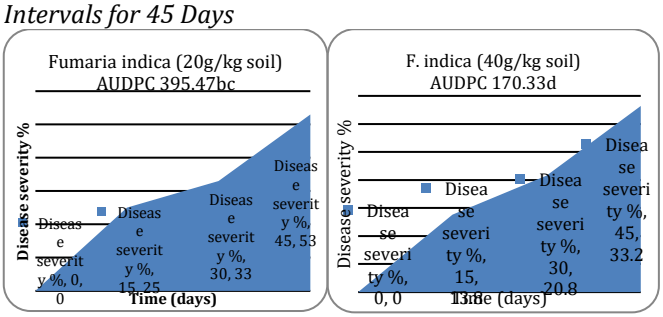


Figure 9(d)

Effect of Inoculated Control on AUDPC of Fusarium wilt of Tomato when Observed Fortnightly Intervals for 45 Days

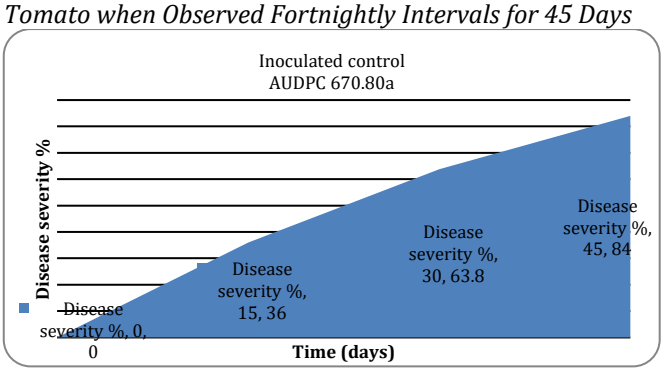


Table 3

Effect of Treatments on Area Under Disease Progress Curve (AUDPC).

Treatments	Doses (g/kg soil)	15 DAT*	30 DAT	45 DAT	AUDPC	% Disease over control
Dodonaea viscosa	20	321.30 (27)	379.50 (37)	480.60 (55)	1181.4	34.52
D. viscosa	40	170.31 (18.6)	225.43 (28.6)	326.53 (46.6)	721.31	44.52
Euphorbia helioscopia	20	345.51 (31.8)	398.40 (40.8)	499.40 (60.8)	1243.19	27.6
E. helioscopia	40	233.57 (24.6)	288.4 (33.6)	389.40 (52.6)	910.15	37.38
Fumaria indica	20	241.55 (25)	294.31 (33)	395.47 (53)	931.25	36.90
F. indica	40	85.17 (13.8)	115.30 (20.8)	170.33 (32.2)	370.15	60.47
Healthy control	0	0.00 (0)	0.00 (0)	0.00 (0)	0.00	0.00
Inoculated control	0	497.71 (36)	565.70 (63.8)	670.80 (84)	1733.21	0.00

*DAT = Days After Transplantation

Effect of Treatments on Plant Height (cm) of Tomato Plants

There were significant (P=0.00) differences between the treatments (Table 4). highest plant height of (87cm) was recorded in the healthy control plants while minimum plant height of (41cm) was observed for the untreated inoculated plants. Among different plant powders, the highest plant height of 82cm was recorded in tomato plants treated with the high dose (40g/kg soil) of *F.indica,* followed bythe high dose of *D.viscosa*(76 cm) and the low dose (20g/kg soil) of *F.indica*(74 cm).The low doses (20g/kg soil) of all the three plants were significantly less effective than their corresponding high doses (40g/kg soil).

Effect of Treatments on Fresh Biomass (g) of Tomato Plants

There were significant differences (P=0.00) among the treatments (Table 4). Maximum fresh biomass of 141.20g was observed in health control while minimum fresh biomass of 45.80g was recorded in the untreated inoculated control plants. Among the different treatments with plant powders, the high dose (40g/kg soil) of *F.indica* was the most effective against Fusarium wilt of tomato resulting in 120g fresh biomass of tomato plants followed by the high dose of *D.viscosa* (97.80g) and the low dose (20g/kg soil) of *F.indica* (84g). The low doses (20g/kg soil) of all the three plants were significantly less effective than their corresponding high doses (40g/kg soil).

Table 4

Effect of different Treatments on Height (cm) and Fresh Biomass (g) of Tomato Plants Infected with FOL, the Cause of Tomato wilt Disease.

Treatments	Plant height (cm)	Fresh biomass (g)
Dodonaea.viscosa 20g/kg soil	69 d	80 d
D.viscosa 40g/kg soil	76 c	97.80 c
Euphorbia.heliscopia 20g/kg soil	60 e	66.40 f
E.heliscopia 40g/kg soil	69 d	73 e
Fumaria indica 20g/kg soil	74 c	84 d
F.indica 40g/kg soil	82 b	120 b
Healthy control	87 a	141.20 a
Inoculated control	41 f	45.80 g

LSD $_{(0.05)}$ for plant height =4.61 LSD $_{(0.05)}$ for fresh biomass =6.41

Effect of Treatments on Yield and Yield Parameters Number of Fruits per Plant

Significant differences (P=0.00) were observed between the treatments (Table 5). The minimum number of fruits were observed in untreated inoculated control pots (0.8) while the maximum number of fruits were recorded in the healthy control (7.4) followed by the high dose (40g/kg soil) of *F.indica* (6.2) and the high dose of *D.viscosa* (4.6).The high doses (40g/kg soil) of all the three plants were found to be significantly more effective than their corresponding low doses (20g/kg soil).

Fruit Weight (g)

Significant (P=0.00) differences were recorded among the treatments (Table 5). The highest fruit weight (63.02g) was observed in the healthy control followed by the high dose (40g/kg soil) of *F.indica* powder (61.70g) and the low dose (20g/kg soil) of the same plant (54.23g). The lowest fruit weight (21.42g) was observed in the untreated inoculated control pots. The high doses of all the three plants were not significantly different from their corresponding low doses.

Fruit Size (mm)

There were significant (P=0.00) differences between the treatments (Table 5). The lowest fruit size was observed in the untreated inoculated control pots (19.39mm). The highest fruit size (43.60mm) was observed in the healthy control followed by the high dose (40g/kg soil) of *F.indica* powder (42.01mm) and the low dose (20g/kg soil) of the same plant (40.30mm).The high doses of all the three plants did not differ significantly from their corresponding low doses.

Table 5

Effect of different Treatments on Yield Parameters of Tomato Plants Infected with FOL, the Cause of Tomato wilt Disease.

Treatments	Number of fruits	Fruit weight (g)	Fruit size (mm)
Dodonaea viscosa 20 g/kg soil	2.8 de	41.05 cd	36.69 ab
D.viscosa 40 g/kg soil	4.6 c	50.05 bc	38.47 ab
Euphorbia helioscopia 20 g/kg soil	1.8 ef	34.03 d	34.38 b
*E.helioscopia*40 g/kg soil	3 d	42.31 cd	37.36 ab
Fumaria indica 20 g/kg soil	3.8 cd	54.23 ab	40.30 ab
*F.indica*40 g/kg soil	6.2 b	61.70 a	42.01 ab
Healthy control	7.4 a	63.02 a	43.60 a
Inoculated control	0.8 f	21.42 e	19.39 c

LSD $_{(0.05)}$ for number of fruits = 1.07, for fruit weight = 9.49, for fruit size =8.18

DISCUSSION

Tomato crops are affected by several diseases, among which the wilt disease caused by *Fusarium oxysporum* f.sp. *lycopersici* (FOL) is a most destructive disease in tomato growing areas (Shivanna *et al*., 2005). Wilt disease can cause severe losses in tomatoes (Anil *et al*.,2015). Fusarium wilt pathogen can survive in plant debris and in soil. Continuous application of chemicals may result in the development of resistant strains (Njue *et al*., 2012). We need to conduct research to find alternative ways for managing this disease.

The antifungal activity of *Dodonaea viscosa, Euphorbia helioscopia* and *Fumaria indica* was investigated in different treatments against *F. oxysporum* f.sp. *lycopersici* causing wilt of tomato. Different doses of the plant powders showed an adverse effect on the growth of the pathogen after one and two weeks of incubation at 25^{0}C, but the treatment having high concentration of *F.indica* powder (16g/L) was more effective and greatly reduced the colony diameter of the pathogen by 72% and 73.17% after one and two weeks of incubation at 25^{0}C respectively while the treatment having low concentration of *E. helioscopia* powder (4g/L) showed the least effect and reduced the colony diameter of the pathogen by 41.33% and 42.68% after one and two weeks of incubation at 25^{0}C respectively. The highest inhibition of the pathogen growth (73.17%) was observed in plates containing potato dextrose agar (PDA) medium amended with the high concentration (16g/L) of *F. indica* powder. Rao *et al*. (2004), Elsadig *et al*. (2007) and Curtis *et al*. (2010)

reported the effectiveness of the plant powder of *F. indica, E. helioscopia, Nerium oleander* and *Xanthium strumarium.* Green manures and powders of medicinal plants, as organic amendments have been reported to be an effective component of the integrated disease management (IDM) against different diseases including Fusarium wilt of tomato (Din *et al*., 2016). Organic amendments to improve soil water holding capacity (Braddy and Weil, 1999). Medicinal plant materials release secondary metabolites such as saponins, lignin, alkaloids, phenols and flavonoids which are antimicrobial in nature. Secondary metabolites were reported in leaves of *D.viscosa* (Pirzada *et al*., 2010) which possess antimicrobial properties. Alkaloid Berberine iodide has been reported to have antifungal and antimicrobial activity which has been isolated from *F.indica*plant. *F.indica*was reported to have alkaloid fuyuziphine which inhibits spore germination of some plant pathogenic fungi such as *Colletotrichum falcatum*, *Curvularia maculans,Ustilago cynodontis* and *Alternaria solani*) (Pandey *et al*., 2007). It has been reported that *F.indica* and *D.viscosa*plants contain secondary metabolites which have antimicrobial compounds which restrict pathogen growth (Thiago *et al*., 2008). Plants secondary metabolites such as flavonoids have been reported to bind with DNA and inhibit synthesis of proteins (Cowan, 1999). *E. helioscopia*h has been reported to have wide pharmacological activities like antibacterial, antifungal, larvicidal and so on (Lanher,1990).

Our results showed that the highest doses of dried powders of *D.viscosa, E.helioscopia* and *F. indica* have strong antimicrobial properties and reduced the pathogen growth significantly. *F. indica* was found to be superior to *E. helioscopia* and *D. viscosa* in reducing the mycelia growth of *F. oxysporum*f. sp. *lycopersici* because it contains two additional constituents; viz., steroids and flavonoids (Rao *et al.*, 2010). The main alkaloids of *F. indica* are berberine, papracinine, fuyuziphine, fumarizine and papraraine (Rao *et al.*, 2010). Therefore, a higher dose such as 40g/kg soil of dried powders of these plants could make an effective component of the IDM against Fusarium wilt of tomato. Cost free and easy availability of *D.viscosa, E.helioscopia* and *F.indica*make them affordable for poor farmers.

In conclusion, IDM strategy should include dried powders, green manures of *F.indica*or other plants to control this disease and minimize the losses. Further studies should be carried out to determine the phytotoxic doses of these plants. Moreover, the effect of these plants on the indigenous microflora, such as *Trichoderma* spp. and other biocontrol agents should be explored.

CONCLUSIONS

It is concluded that the plant powders tested in this study, especially *F. indica* is effective in reducing disease severity of Fusarium wilt of tomato and improving the growth and enhancing the yield of tomatoes significantly. Dose of 40g/kg soil of all these three tested plant powders can be included in integrated disease management (IDM) strategy against Fusarium wilt of tomato. Similarly, further studies should be conducted on the phytotoxicity of these plants by using higher doses than 40g/kg soil to know its effect on indigenous microflora.

Author's Contribution

Conceptualization: F, FR
Methodology: SU, AM
Formal analysis: MNK, DM, AN, ZH
Writing reviews and editing: MY, BA, TI
All authors have read and agreed to the published version.

REFERENCES

1. Adisa, I. O., Reddy Pullagurala, V. L., Rawat, S., Hernandez-Viezcas, J. A., Dimkpa, C. O., Elmer, W. H., ... & Gardea-Torresdey, J. L. (2018). Role of cerium compounds in Fusarium wilt suppression and growth enhancement in tomato (Solanum lycopersicum). *Journal of agricultural and food chemistry*, *66*(24), 5959-5970. https://doi.org/10.1021/acs.jafc.9b06840
2. Anil Kumar, R., & Raj Kumar, H. G. (2015). In vitro antifungal activity of some plant extracts against Fusariumoxysporum f. sp. lycopersici. *Asian Journal of Plant Science and Research*, *5*(1), 22-27.
3. Jones Jr, J. B. (2007). *Tomato plant culture: in the field, greenhouse, and home garden*. CRC press. https://doi.org/10.1201/9781420007398
4. Brady, N. C., & Weil, R. R. (1999). Soil aeration and temperature. *The Nature and Properties of Soil, 12th ed.; Prentice Hall: New York, NY, USA*, 265-306.
5. Brandt, S., Pék, Z., Barna, É., Lugasi, A., & Helyes, L. (2006). Lycopene content and colour of ripening tomatoes as affected by environmental conditions. *Journal of the Science of Food and Agriculture*, *86*(4), 568-572. https://doi.org/10.1002/jsfa.2390
6. Chohan, T. Z., & Ahmad, S. (2008). An assessment of tomato production practices in Danna Katchely, Azad Jammu Kashmir. *Pak J Life Soc Sci*, *6*, 96-102.
7. Chopra, R. N., & Nayar, S. L. (1956). *Glossary of Indian medicinal plants*. Council of scientific and Industrial Research.
8. Cowan, M. M. (1999). Plant products as antimicrobial agents. *Clinical microbiology reviews*, *12*(4), 564-582. https://doi.org/10.1128/cmr.12.4.564
9. Curtis, H., Noll, U., Störmann, J., & Slusarenko, A. J. (2004). Broad-spectrum activity of the volatile phytoanticipin allicin in extracts of garlic (Allium sativum L.) against plant pathogenic bacteria, fungi and Oomycetes. *Physiological and molecular plant pathology*, *65*(2), 79-89. https://doi.org/10.1016/j.pmpp.2004.11.006
10. Di Pietro, A., Madrid, M. P., Caracuel, Z., Delgado-Jarana, J., & Roncero, M. I. G. (2003). Fusarium oxysporum: exploring the molecular arsenal of a vascular wilt fungus. *Molecular plant pathology*, *4*(5). https://doi.org/10.1046/j.1364-3703.2003.00180.x
11. Din, N., Ahmad, M., Siddique, M., Ali, A., Naz, I., Ullah, N., & Ahmad, F. (2016). Phytobiocidal management of bacterial wilt of tomato caused by Ralstonia solanacearum (Smith) Yabuuchi. *Spanish Journal of agricultural research*, *14*(3), e1006-e1006. https://doi.org/10.5424/sjar/2016143-9012
12. Elsadig, E., Fatma, A. B., Iman, A. S., & Tabisam, K. (2007). Analysis of Phytoalexins by High Performance Liquid Chromatography-Mass Spectrometry (HPLC-MS) following Induction in Nerium oleander. In *Bot. Pl. Biol. Joint Congress* (Vol. 1019).
13. Gatahi, D. M. (2020). Challenges and opportunities in tomato production chain and sustainable standards. *International*

Journal of Horticultural Science and Technology, *7*(3), 235-262.
https://doi.org/10.22059/ijhst.2020.300818.361
14. Getie, M., Gebre-Mariam, T., Rietz, R., Höhne, C., Huschka, C., Schmidtke, M., ... & Neubert, R. H. H. (2003). Evaluation of the anti-microbial and anti-inflammatory activities of the medicinal plants Dodonaea viscosa, Rumex nervosus and Rumex abyssinicus. *Fitoterapia*, *74*(1-2), 139-143. https://doi.org/10.1016/S0367-326X(02)00315-5
15. GoP. (2018). Agricultural Statistics Book. Ministry of National Food Security and Research, Government of Pakistan, Islamabad, Pakistan.
16. Gupta, V. P., Bochow, H., Dolej, S., & Fischer, I. (2000). Plant growth-promoting Bacillus subtilis strain as potential inducer of systemic resistance in tomato against Fusarium wilt/Ein das Pflanzenwachstum fördernder Bacillus subtilis-Stamm als potentieller Resistenzinduktor gegen die Fusarium-Welke an Tomaten. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz/Journal of Plant Diseases and Protection*, 145-154.
17. Kirtikar, K. R., & Basu, B. D. (1918). *Indian medicinal plants* (Vol. 2). publisher not identified Basu, Bhuwaneśwari Âśrama.
18. Kuć, J. (1982). Induced immunity to plant disease. *Bioscience*, *32*(11), 854-860. https://doi.org/10.2307/1309008
19. Lanhers, M. C., Fleurentin, J., Cabalion, P., Rolland, A., Dorfman, P., Misslin, R., & Pelt, J. M. (1990). Behavioral effects of Euphorbia hirta L.: sedative and anxiolytic properties. *Journal of ethnopharmacology*, *29*(2), 189-198. https://doi.org/10.1016/0378-8741(90)90055-X
20. Lanhers, M. C., Fleurentin, J., Dorfman, P., Mortier, F., & Pelt, J. M. (1991). Analgesic, antipyretic and anti-inflammatory properties of Euphorbia hirta. *Planta medica*, *57*(03), 225-231. https://doi.org/10.1055/s-2006-960079
21. Madden, L. V., Hughes, G., & Bosch, F. V. D. (2007). *The study of plant disease epidemics* (pp. xiv+-421).
22. Njue, A. W., Njogu, E. M., Otaye, D. O., Cheplogoi, P. K., & Omolo, J. O. (2012). In vitro inhibition of tomato Fusarium wilt causative agent by zearalenone from a soil inhabiting fungus. *African Journal of Biotechnology*, *11*(72), 13683-13689. https://doi.org/10.5897/AJB12.501
23. Noonari, S., Memon, M. I. N., Solangi, S. U., Laghari, M. A., Wagan, S. A., Sethar, A. A., ... & Panhwar, G. M. (2015). Economic implications of tomato production in naushahro feroze district of Sindh Pakistan. *Research on Humanities and Social Sciences*, *5*(7), 158-70. https://doi.org/10.13140/RG.2.1.2186.0325
24. Orhan, I. E., Şener, B., & Musharraf, S. G. (2012). Antioxidant and hepatoprotective activity appraisal of four selected Fumaria species and their total phenol and flavonoid quantities. *Experimental and toxicologic pathology*, *64*(3), 205-209. https://doi.org/10.1016/j.etp.2010.08.007
25. Pandey, M. B., Singh, A. K., Singh, A. K., & Singh, U. P. (2007). Inhibitive effect of fuyuziphine isolated from plant (Pittapapra)(Fumaria indica) on spore germination of some fungi. *Mycobiology*, *35*(3), 157-158. https://doi.org/10.4489/MYCO.2007.35.3.157
26. Pirzada, A. J., Shaikh, W., & Usmanghani, K. (2010). Antifungal activity of Dodonaea viscosa Jacq extract on pathogenic fungi isolated from super ficial skin infection. *Pakistan journal of pharmaceutical sciences*, *23*.
27. Pritesh, P., & Subramanian, R. B. (2011). PCR based method for testing Fusarium wilt resistance of tomato. *African Journal of Basic and Applied Sciences*, *3*(5), 222.
28. Rajeswari, V. D., Gajalakshmi, S., Jayanthi, P., & Vijayalakshmi, S. (2011). Pharmacological activities of Dodonaea viscosa: a perspective review.
29. Rao, K. V. B., Karthik, L., Elumalai, E. K., Srinivasan, K., & Kumar, G. (2010). Antibacterial and antifungal activity of Euphorbia hirta l. Leaves: A comparative study. *Journal of Pharmacy Research*, *3*(3), 548.
30. Rekah, Y., Shtienberg, D., & Katan, J. (2000). Disease development following infection of tomato and basil foliage by airborne conidia of the soilborne pathogens Fusarium oxysporum f. sp. radicis-lycopersici and F. oxysporum f. sp. basilici. *Phytopathology*, *90*(12), 1322-1329. https://doi.org/10.1094/PHYTO.2000.90.12.1322
31. Rozlianah, F. S., & Sariah, M. (2010). Characterization of Malaysian isolates of Fusarium from tomato and pathogenicity testing. https://doi.org/10.3923/jm.2006.266.272
32. Shivanna, M. B., Meera, M. S., Kubota, M., & Hyakumachi, M. (2005). Promotion of growth and yield in cucumber by zoysiagrass rhizosphere fungi. *Microbes and environments*, *20*(1), 34-40. https://doi.org/10.1264/jsme2.20.34
33. Song, W., Zhou, L., Yang, C., Cao, X., Zhang, L., & Liu, X. (2004). Tomato Fusarium wilt and its chemical control strategies in a hydroponic system. *Crop protection*, *23*(3), 243-247. https://doi.org/10.1016/j.cropro.2003.08.007
34. Srobar, S. (1978). The influence of temperature and pH on the growth of mycelium of the causative agents of Fusarioses in wheat in Slovakia Czechoslovakia. *Sbornik Ustav Vedeckotechnickych-Informaci-Ochrana-Rostlin.–1978.–14.–P*, 269-274.
35. de Sousa Araújo, T. A., Alencar, N. L., de Amorim, E. L. C., & de Albuquerque, U. P. (2008). A new approach to study medicinal plants with tannins and flavonoids contents from the local knowledge. *Journal of ethnopharmacology*, *120*(1), 72-80. https://doi.org/10.1016/j.jep.2008.07.032
36. Vijaya, K., & Ananthan, S. (1997). Microbiological screening of Indian medicinal plants with special reference to enteropathogens. *The Journal of Alternative and Complementary Medicine*, *3*(1), 13-20. https://doi.org/10.1089/acm.1997.3.13
37. Wang, C., Zhang, S., Hou, R., Zhao, Z., Zheng, Q., Xu, Q., ... & Xu, J. R. (2011). Functional analysis of the kinome of the wheat scab fungus Fusarium graminearum. *PLoS pathogens*, *7*(12), e1002460. https://doi.org/10.1371/journal.ppat.1002460