RESEARCH ARTICLE AGROBIOLOGICAL RECORDS
ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
Open Access Journal

STRATEGIES FOR THE INTEGRATED MANAGEMENT OF TOMATO WILT

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ABSTRACT

Tomato wilt is a significant yield-reducing disease in tomato crops, caused primarily by Fusarium species, including Fusarium verticillioides, Fusarium oxysporum, and Fusarium equiseti. These wilt-causing fungal pathogens can persist in soil for up to 10 years, severely impacting crop health and yield, resulting in substantial economic losses for farmers. The objective of this study is to develop eco-friendly control methods for managing tomato wilt disease. In this study, fungal pathogens associated with tomato wilt were isolated from different parts of infected plants and identified based on their morphological and microscopic characteristics. Management strategies were evaluated using various treatments, including acidic soil, alkaline soil, neutral soil, chemical control, biocontrol and vermicompost, both individually and in combination. Soil acidity was adjusted using humic acid, alkalinity with poultry manure, and neutrality was maintained with water. For chemical control, Carbendazim was employed, and *Trichoderma harzianum* was utilized for biocontrol. The experiment comprised 21 treatments, each with three replications, including a control group with three replications. The study was conducted in pots using a Completely Randomized Design (CRD). Seven parameters were noted; number of flowers, number of fruits, plant shoot length (cm), total number of branches, total number of leaves, yellowing and drying of leaves, and wilting %. Recorded data were statistically analyzed. The treatments T17 (Carbendazim + Vermicompost), T7, T13, T4, T8, T9, T19, T21, T20, T18, T15, T10, T12, T14, T16, T11, T5, T6, T2, T1, and T3 reduced wilting by 84, 82, 81, 80, 80, 79, 79, 78, 78, 74, 74, 74, 73, 73, 72, 71, 70, 69, 64, 60, and 51%, respectively. All treatments promoted plant growth. The reduction in wilting observed in T17-treated plants and all other treatments was significantly greater than that in the control and T3 (Water) treated plants.

***Keywords*:** Tomato, Plant protection, IDM

Article History (ABR-24-241) || Received: 22 Jun 2024 || Revised: 15 Jul 2024 || Accepted: 12 Aug 2024 || Published Online: 17 Aug 2024

1. INTRODUCTION

Tomatoes are extremely nutritious, containing vitamins A, B, and C. Other vital minerals contained in tomatoes include β-carotene, lycopene, and phosphorus (Tahir et al. 2018). It is cooked with vegetables and used as a main constituent in salads. Many biotic factors have restricted tomato production, and despite concerted efforts to increase output, its production continues to suffer. Viral, bacterial, nematode and fungal pathogens continue to be the most serious threats to tomato output (SG 2024). Wilt-causing substances are the most serious concern among tomato diseases. Bacterial wilt caused by the pathogen *Ralstonia solanacearum* was documented to cause 26% fresh fruit damage. Tomato leaf curl has been reported to cause up to 40% loss in Sindh, Pakistan (Wu et al. 2023). The destructive pathogens are Ascomycota pathogens of the order Hypocreales. They have posed a greater threat to tomato output than any other pathogen (Wang et al. 2023). Because of their catastrophic consequences, Verticillium wilt and Fusarium wilt are the two most economically powerful diseases. In contrast to fusarium wilt, which is more catastrophic in warm temperatures, Verticillium is more catastrophic in cool environments (El-Aswad et al. 2023). Because of their similar unclear symptoms, distinguishing the two on symptomology is challenging. Fusarium spp. are key contributors to tomato decline, accounting for 10-50% of global losses and 10-90% in warmer regions of Pakistan (Lagopodi et al. 2002). *F. verticillioides*, *F. proliferatum*, and *F. solani* also infect and cause disease in tomatoes like plant withering (Zhang et al. 2016). The wilt disease of tomato causes tomato plants to wilt. It's a serious disease that affects both field and greenhouse-grown tomatoes globally. When humid conditions predominate on fruit at the maturity stage, the disease rises in tomato fields. Wilt disease tomato

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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symptoms include vein clearing, leaf yellowing, leaf margin curling, adventitious root formation, defoliation, stunting, necrosis of leaf blades, and eventually death of the entire plant (Srinivas et al. 2019).

Fusarium wilt is a devastating tomato disease caused by the fungal pathogen FOL (*Fusarium oxysporum f.sp. lycopersici*), which causes significant losses to the farming community (Akhter et al. 2016). Fusarium survival and infection are favored by acidic soil with a pH of 5-6 and a temperature of 25-28°C (Srivastava et al. 2012). *Fusarium oxysporum* can be found in soil as chlamydospores, microconidia, and macroconidia. Infected tissues or soil might include all stages of the fungus. Fusarium wilt causes serious vascular tissue damage and foliar damage early in the growth cycle, resulting in greater stunting of infected plants. Fusarium pathogen causes necrotic patches and yellow spots on the exterior edges of leaves (Okungbowa and Shittu, 2012). *Fusarium equiseti* is a soil fungus that can attack tubers, also roots, fruits, and seeds of a wide range of crop plants. *F. equiseti* has been involved in the root blemish.

Fungicides are the primary tool for controlling plant diseases. Fungicides have an instant impact on pathogen development and lead to greater productivity via improved, stabilized yields at a lower cost of production (Zafar et al. 2020; Zafar et al. 2022). Fungicides suppress the growth of disease-causing pathogens and in this way control disease and promote plant growth (Weber et al. 2018). Carbendazim-based fungicides provide effective disease management and broad-spectrum systemic fungicide, as well as show good results against the wilt of tomatoes (Brent and Hollomon 1998).

The vermicompost utilized to biologically manage Tomato Fusarium Wilt is environmentally friendly and represents a promising strategy for controlling the Fusarium wilt of tomato (Roubalova et al. 2020). Keeping in view the importance of all above-mentioned strategies to manage tomato wilt disease, the present study was carried out with the objective given below. The objectives of the present study are isolation, purification, and identification of tomato wilt-associated fungal pathogen and its integrated disease management by manipulation of soil pH, vermicompost, bio-control agent and eco-friendly synthetic chemical to reduce the risk of their potential residual effect.

2. MATERIALS AND METHODS

2.1. Sowing of Healthy Tomato Seedlings in Pots

Experiment conducted at the research area Department of Plant Pathology, University of Agriculture, Faisalabad. Tomato seedlings collected from Vegetable Research Institute, AARI, Faisalabad. Seedlings were transplanted in pots using three replications for each treatment. Factors necessary for optimum growth i.e. fertilizer, irrigation, and weed eradication timely applied.

2.2. Collection of Infected Samples of Tomato

Infected samples were collected from the Vegetable Research Area, AARI, and Horticulture Research Area, UAF, Faisalabad. Plants reflecting the symptoms of wilting and necrosis were collected. Isolation of pathogen from these infected samples carried out in Disease Diagnostic Lab, UAF, Faisalabad. Infected roots and stems of diseased plants were collected in polythene bags and stored at 4°C for future use.

2.3. Culture Media Preparation

39 grams of potato dextrose agar mixed in 1000mL distilled water in the flask and kept on a magnetic stirrer for thorough mixing. Autoclaved at 121°C and 15psi pressure to sterilize. An antibiotic, streptomycin was added to inhibit the bacterial growth. Sterilized media was poured into Petri plates in a laminar flow chamber under aseptic conditions.

2.4. Isolation of Pathogen from Infected Samples

Infected samples were washed under tap water and dried. Samples were cut (1-2cm) along with some healthy portions and washed with distilled water. The surface was sterilized with 70% ethanol and washed with distilled water and finally dried on sterilized filter paper. Finally, 3 to 4 pieces of prepared samples were placed on plates having PDA medium. These cultured plates were incubated at 26-28°C with alternate light and darkness of 12h.

2.5. Purification and Identification of Associated Fungus

Grown fungal pathogens sub-cultured in separate plates on PDA by using single hyphal tip in order to purify them. Samples were analyzed under the compound microscope. Morphological characters i.e., colony appearance, colony texture, and colony color examined under it. Whereas the shape of hyphae, spore size, and fruiting structures were analyzed under the microscope. The associated fungal pathogen is recognized and checked into different groups based on morphological characteristics. Identification of pathogen based on available literature comprising morphology, including colony color, size, and spore shape, structure, and growth pattern. The identified fungus was *Fusarium oxysporum f.sp. lycopersici* (Toussoun and Nelson 1976).

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2.6. Multiplication of *Fusarium oxysporum f.sp. lycopersici*

Multiplication of *Fusarium oxysporum f.sp. lycopersici* in petri plates having PDA under a laminar flow chamber.

2.6.1. Preparation of Inoculum

Two-week-old pure culture of isolated pathogen used to prepare spore suspension. Spores were collected by putting 10 mL of sterile water into each petri dish with pure cultivated fungus, then gently scraping the mycelium surface with a sterilized spatula to mix it in distilled water in a laminar flow. After spore suspension preparation, carefully pass through the strainer or muslin cloth to remove the mycelium and culture media. Quantification of spore concentration ($1x10^4$) was carried out with the help of a hemocytometer and finally preserved at 4°C in falcon tubes.

2.6.2. Pathogenicity

Inoculation of *Fusarium oxysporum f.sp. lycopersici* spore suspension 10^4 spores/ml applied in each pot with irrigation water on the soil of 1.5-month-old seedlings of tomato.

2.7. Management of Tomato Wilt using different Treatments

For management of tomato wilt, different treatments alone and their combinations applied to the pots.

2.7.1. Treatment Application in Pots

Treatments were applied after two weeks of pathogenicity. Humic acid make soil acidic so for making soil pH lower, add 10g of humic acid in 1000mL water to make 1% solution and from this solution 175mL applied in pots with irrigation water. Poultry manure makes soil alkaline so for making soil pH higher, poultry manure is applied in pots because poultry manure has a higher pH and is applied with irrigation water 1:3 poultry manure: soil. For neutral soil just apply water in pots.

For chemical control, Carbendazim applied is a systemic fungicide and controls the wilt disease of tomatoes. Carbendazim mixed in 1L of sterilized water in a volume of 100mL, and the resulting chemical solution sprayed on infected leaves.

For biocontrol, *Trichoderma harzianum* applies and it has an antagonistic effect on fungal pathogens and eco-friendly management. Before applying to diseased plant, for disease management purpose *Trichoderma harzianum* grown in autoclaved wheat straw. The wheat straw was wetted with sterilized water and the culture bits were mixed in with the wheat straws. The straws were packaged in polythene plastic bags, which were then kept in an incubator for one week. *Trichoderma harzianum* 125g was applied to the soil of each pot with irrigation water after the antagonistic microflora had grown.

Vermicompost (A product of earthworm digestion) is an eco-friendly and organic management of the wilt disease of tomatoes. Vermicompost obstructs plant diseases owing to decreased pathogenic microbes and increased hostile microorganisms. Applied with 1:3 (Vermicompost: Soil) with irrigation water in pots. The detail of Total of 22 treatments are given in Table 1.

2.7.2. Data Collection

These 7 parameters were noted for each treatment:

1. Number of flowers
2. Number of fruits
3. Plant shoot length (cm)
4. Total number of branches
5. Total number of leaves
6. Yellowing and drying of leaves
7. Wilting %

2.8. Data Analysis

Statistical analysis of data was performed for disease intensity and management by using the Statistix 8.1. Data was analyzed by analysis of variance (ANOVA) using CRD (Completely randomized design) and significance differences were checked at probability level 5 or 1% (Steel et al. 1997). Analysis of variances followed by Tukey's test. Results were reported as the mean of replications.

3. RESULTS

3.1. Number of Flowers in 3rd and 5th Week

The analysis of variance revealed that the differences among all treatments were non-significant for the number of flowers in 3rd week, whereas all the treatments showed highly significant differences in the number of flowers in 5th week (Table 2). The mean performance under all treatments in 3rd week is graphically represented in Fig. 1. T20 (16.667) and T22 (control) (16) showed the highest mean and T3 (2.6667) showed the lowest mean for the number of flowers. T20 (16.667) and T22 (control) (16) showed the highest mean and T3 (2.6667) showed the lowest mean for the number of flowers (Fig. 1).

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Table 1: All treatments description used in experiment

Treatment/Treatment combinations	Description	Maintenance strategy
T1	Acidic soil	Humic acid applied
T2	Alkaline soil	Poultry manure applied
T3	Neutral soil	Water applied
T4	Chemical	Carbendazim applied
T5	Biocontrol	*Trichoderma harzianum* applied
T6	Vermi-compost	Vermi-compost applied
T7	T1+T4	Humic acid + Carbendazim applied
T8	T2+T4	Poultry manure + Carbendazim applied
T9	T3+T4	Water + Carbendazim applied
T10	T1+T5	Humic acid + *Trichoderma harzianum* applied
T11	T2+T5	Poultry manure + *Trichoderma harzianum* applied
T12	T3+T5	Water + *Trichoderma harzianum* applied
T13	T4+T5	Carbendazim + *Trichoderma harzianum* applied
T14	T1+T6	Humic acid + Vermi-compost applied
T15	T2+T6	Poultry manure + Vermi-compost applied
T16	T3+T6	Water + Vermi-compost applied
T17	T4+T6	Carbendazim + Vermi-compost applied
T18	T5+T6	*Trichoderma harzianum* + Vermi-compost applied
T19	T1+T4+T5+T6	Humic acid + Carbendazim + *Trichoderma harzianum* + Vermi-compost applied
T20	T2+T4+T5+T6	Poultry manure+Carbendazim + *Trichoderma harzianum* + Vermi-compost applied
T21	T3+T4+T5+T6	Water + Carbendazim + *Trichoderma harzianum* + Vermi-compost applied
Control	No treatment applied	Water applied

Table 2: The Mean square values of various traits in tomato under different treatments at 3rd and 5th week of experiment.

Traits	SOV	Treatments	Error
	DF	21	44
Number of flowers	3rd week	45.7	41.60
	5th week	84.06**	34.74
Number of fruits	3rd week	1.60	1.70
	5th week	3.04	3.12
Plant shoot length	3rd week	58.03	47.60
	5th week	70.40	41.47
Total number of Branches	3rd week	1.40	1.90
	5th week	1.27	1.74
Total Number of Leaves	3rd week	43.30	34.60
	5th week	63.43**	33.77
Yellowing and Drying of Leaves	3rd week	3.55**	1.60
	5th week	9.87**	2.15
Wilting %	3rd week	46.03**	20.52
	5th week	196.43**	5.41

SOV = Source of variance, DF = Degree of freedom, SS= Sum of Squares, MS= Mean Square; ** = P< 0.01 Highly significant, * = P< 0.05 Significant, NS = P>0.05 non-significant

The mean performance under all treatments in the 5th week is graphically represented in Fig. 1. Both T17 (28.333) and T20 (27.333) showed the highest mean and T1 (7.6667) showed the lowest mean for the number of flowers. The pairwise mean comparison test showed variation among all the treatments. This means that those who did not share the same letter are significantly different, while those who shared the same letter are non-significantly different. Both T17 (28.333) and T20 (27.333) showed the highest mean and T1 (7.6667) showed the lowest mean for the number of flowers.

3.2. Number of Fruits in 3rd and 5th Week

The analysis of variance revealed that the differences among all treatments were non-significant for the number of fruits in 3rd week and 5th week (Table 2). The mean performance under all treatments in 3rd week is graphically represented in Fig. 2. T19 and T20 (2.333) showed the highest mean and T3, T6, T7, T9, and T10 (0) had the lowest mean for the number of fruits. T19 and T20 (2.333) showed the highest mean and T3, T6, T7, T9, and T10 (0) had the lowest mean for the number of fruits (Fig. 2).

The mean performance under all treatments in the 5th week is graphically represented in Fig. 4. Both T19 (6) and T20 (5) showed the highest mean and T3 (1.3333) showed the lowest mean for the number of fruits. Both T19 (6) and T20 (5) showed the highest mean and T3 (1.3333) showed the lowest mean for the number of fruits (Fig. 2).

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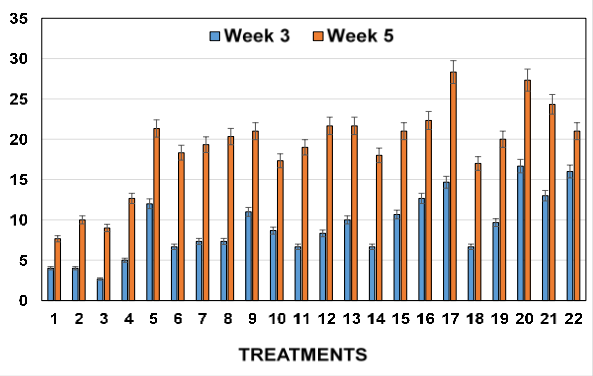

Fig. 1: Mean performance of all the treatments for number of flowers at 3rd and 5th week of experiment.

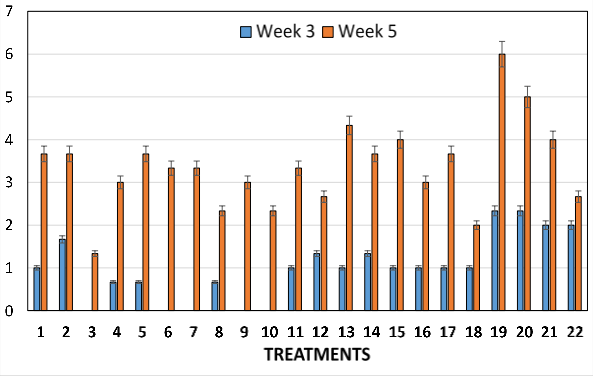

Fig. 2: Mean performance of all the treatments for the number of flowers at 3rd and 5th week of experiment.

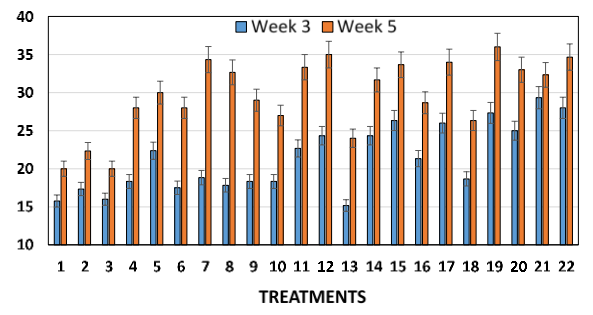

Fig. 3: Mean performance of all the treatments for plant shoot length at 3rd and 5th week of experiment.

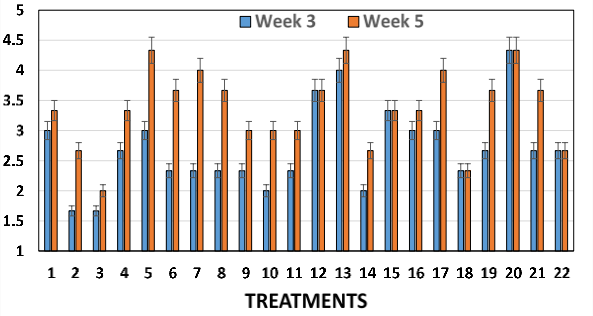

Fig. 4: Mean performance of all the treatments for total number of branches at 3rd and 5th week of experiment.

3.3. Plant Shoot Length in 3rd and 5th Week

The analysis of variance revealed that the differences among all treatments were non-significant for shoot length at 3rd week and 5th week. The mean performance under all treatments is graphically represented in Fig. 3. T21 showed the highest mean (29.333cm) and T13 showed the lowest mean (15.167cm) for total plant shoot length. T21 showed the highest mean (29.333cm) and T13 showed the lowest mean (15.167cm) for total plant shoot length (Fig. 3). The mean performance under all treatments in the 5th week is graphically represented in (Fig. 3). T19 showed the highest mean (36cm) and T1 & T3 showed the lowest mean (20 cm) for total plant shoot length. T19 showed the highest mean (36 cm) and T1 & T3 showed the lowest mean (20 cm) for total plant shoot length (Fig. 3).

3.4. Total Number of Branches in 3rd and 5th Week

The analysis of variance revealed that the differences among all treatments were non-significant for the total number of Branches in 3rd week and 5th week. The mean performance under all treatments is graphically represented in (Fig. 4). Both T20 (4.3333) and T13 (4) showed the highest mean and T2 and T3 (1.6667) showed the lowest mean for the total number of branches (Fig. 4).

Both T20 (4.3333) and T13 (4) showed the highest mean and T2 and T3 (1.6667) showed the lowest mean for the total number of branches. The mean performance under all treatments in 5th week is graphically represented in (Fig. 4). Both T13 and T20 showed the highest mean (4.3333) and T3 (2) showed the lowest mean for the total number of branches. Both T13 and T20 showed the highest mean (4.3333) and T3 (2) showed the lowest mean for the total number of branches.

3.5. Total Number of Leaves in 3rd and 5th Week

The analysis of variance revealed that the differences among all treatments were non-significant for the total number of leaves in 3rd week. Instead, the differences were significant in the 5th week (Table 2). The mean performance under all treatments in 3rd week is graphically represented in (Fig. 5). Both T12 and T15 showed the highest mean (24) and T1 (12.667) showed the lowest mean for the total number of leaves. Both T12 and T15 showed the highest mean (24) and T1 (12.667) showed the lowest mean for the total number of leaves (Fig. 5). The

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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mean performance under all treatments in the 5th week is graphically represented in (Fig. 5). Both T17 (36.667) and T12 (34.667) showed the highest mean and T1 (19.333) showed the lowest mean for the total number of leaves. Both T17 (36.667) and T12 (34.667) showed the highest mean and T1 (19.333) showed the lowest mean for the total number of leaves (Fig. 5).

3.6. Yellowing and Drying of Leaves in 3rd and 5th week

The analysis of variance revealed highly significant differences in yellowing and drying of leaves among all treatments by the 3rd week. Similarly, highly significant differences were observed among all treatments by the 5th week (Table 2). Fig. 6 graphically represents the mean performance under all treatments in the 3rd week. Both T22 (control) and T5 had the highest mean (6.6667), while T4 (3) had the lowest mean for yellowing and drying of leaves. Fig. 6 graphically represents the mean performance under all treatments in the 5th week. T22 (control) had the highest mean (11.667), and T4 had the lowest mean (5) for yellowing and drying of leaves.

3.7. Wilting in 3rd and 5th Week

The analysis of variance revealed that all treatments showed highly significant differences for wilting% in 3rd week as well as in the 5th week (Table 2). The mean performance under all treatments is graphically represented in Fig. 7. Both T6 (34.145%) and T22 (control) (33.868%) showed the highest mean and T17 (20.436%) showed the lowest mean for wilting%. Both T6 (34.145) and T22 (control) (33.868) showed the highest mean and T17 (20.436) showed the lowest mean for wilting%. The mean performance under all treatments in the 5th week is graphically represented in Fig. 7. Both T3 (49.379%) and T22 (control) (41.325%) showed the highest mean and T17 (15.123%) showed the lowest mean for wilting%. Both T3 (49.379%) and T22 (control) (41.325%) showed the highest mean and T17 (15.123%) showed the lowest mean for wilting % (Fig. 7).

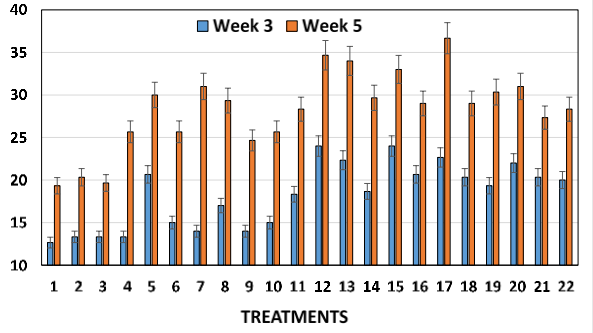

Fig. 5: Mean performance of all the treatments for total number of leaves at 3rd and 5th week of experiment.

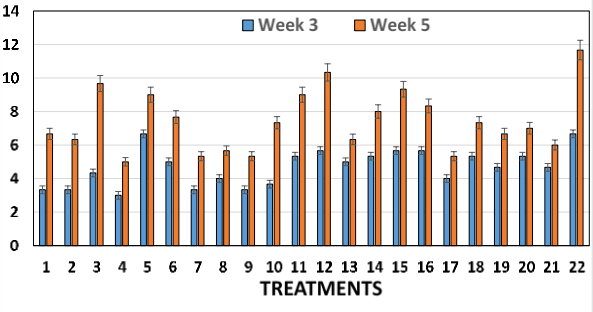

Fig. 6: Mean performance of all the treatments for yellowing and drying of leaves at 3rd and 5th week of experiment.

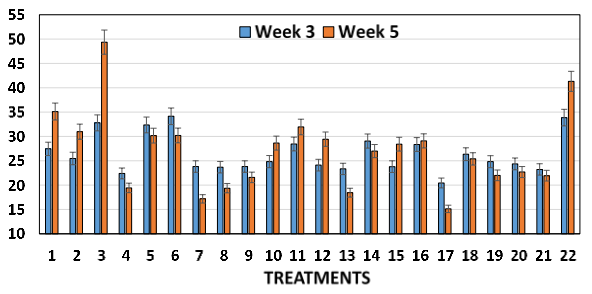

Fig. 7: Mean performance of all the treatments for wilting% at 3rd and 5th week of experiment.

4. DISCUSSION

Tomato wilt is caused by the soil-borne fungal pathogen Fusarium oxysporum f. sp. lycopersicum (FOL). The severity of disease symptoms increases in sandy, acidic soils. The pathogen can persist in the soil for up to ten years. Wilt symptoms are more severe in warmer soils (34°C) compared to cooler soils (17-20°C) (Di Pietro et al. 2003). Fusarium infection and survival in soil are favored by acidic conditions (pH 5-6) and a temperature range of 25-28°C (Sherwood 1920; Srivastava et al. 2012).

Humic acid has been shown to inhibit the growth and sporulation of numerous phytopathogenic fungi.

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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Specifically, it greatly inhibits the sporulation and radial growth of F. oxysporum f. sp. lycopersici (Abdel-Monaim et al. 2012). Additionally, humic acid stimulates plant growth by enhancing cell division and optimizing the uptake of water and nutrients, particularly phosphorus, nitrogen, and potassium, which are essential for plant growth. It also increases cell membrane permeability, improves soil conditions, and influences enzyme activity, protein synthesis, and biomass production (Patil 2010).

In our study, humic acid alone and in combination with other treatments significantly reduced wilting and promoted plant growth. We found that T1 (Humic acid), T7 (Humic acid + Carbendazim), T10 (Humic acid + Trichoderma harzianum), T14 (Humic acid + Vermicompost), and T19 (Humic acid + Carbendazim + Trichoderma harzianum + Vermicompost) reduced wilting by 60, 82, 74, 73, and 79%, respectively. All these treatments promoted the number of flowers, fruits, branches, and leaves, enhanced plant shoot length, and decreased wilting, yellowing, and drying of leaves. Compost Chicken-manure is a beneficial organic amendment with degrees of bio-fertilizer and antagonistic activity against *F. oxysporum*. Chicken-manure composted is proven to increase soil quality, nutritional, chemical and physical quality, and microbial activity (Garcia et al. 1992; Van Dang et al. 2021; Chen et al. 2024). In our study Poultry manure alone and combination with others give significant results in reducing wilting and also promote growth, we found that T2 (Poultry manure), T8 (Poultry manure + Carbendazim), T11 (Poultry manure + *Trichoderma harzianum)*, T15 (Poultry manure + Vermicompost), T20 (Poultry manure + Carbendazim + *Trichoderma harzianum* + Vermicompost) reduced wilting 64, 80, 71, 74, and 78%, respectively and all these treatments promote the number of flowers, fruits, branches, leaves and promote plant shoot length and decrease wilting, yellowing and drying of leaves.

Carbendazim fungicide provides effective disease control and systemic fungicides give excellent results against tomato wilt (Brent and Hollomon 1998; Chaudhari and Patel 2024). IDM of FOL on tomato utilising spent mushroom compost, *T. harzianum*, soil solarization and chemical approach (Carbendazim), considerably reduced fusarium occurrence. Plants treated with combination of *T. harzianum* + solarized soil + spent mushroom compost exhibited a considerable reduction in *F. oxysporum f.sp. lycopersici* disease intensity (Salim et al. 2017). In our study Carbendazim alone and in combination with others give significant results in reducing wilting and promoting growth, we found that T4 (Carbendazim), T7 (Humic acid + Carbendazim), T8 (Poultry manure + Carbendazim), T9 (Water + Carbendazim), T13 (Carbendazim + *Trichoderma harzianum)*, T17 (Carbendazim + Vermicompost), T19 (Humic acid + Carbendazim + *Trichoderma harzianum* + Vermi-compost), T20 (Poultry manure + Carbendazim + *Trichoderma harzianum* + Vermi-compost), T21 (Water + Carbendazim + *Trichoderma harzianum* + Vermi-compost) reduced wilting 80, 82, 80, 79, 81, 84, 79, 78, and 78%, respectively and all these treatments promote number of flowers, fruits, branches, leaves and promote plant shoot length and decrease wilting, yellowing and drying of leaves.

Trichoderma has been shown to diminish the occurrence of Fusarium wilt disease in tomatoes (Verma et al. 2016; Zafar et al. 2020). It boosts plant growth and agricultural yield while also inducing systemic and localised resistance to a variety of plant diseases (Kareem et al. 2016). In our study *Trichoderma harzianum* alone and in combination with others give significant results in reducing wilting and also promoting growth, we found that T5 (*Trichoderma harzianum)*, T10 (Humic acid + *Trichoderma harzianum*), T11 (Poultry manure + *Trichoderma harzianum)*, T12 (Water + *Trichoderma harzianum*), T13 (Carbendazim + *Trichoderma harzianum)*, T18 (*Trichoderma harzianum* + Vermi-compost), T19 (Humic acid + Carbendazim + *Trichoderma harzianum* + Vermi-compost), T20 (Poultry manure + Carbendazim + *Trichoderma harzianum* + Vermi-compost), T21 (Water + Carbendazim + *Trichoderma harzianum* + Vermi-compost) reduced wilting 70, 74, 71, 73, 81, 74, 79, 78, and 78%, respectively and all these treatments promote the number of flowers, fruits, branches, leaves and promote plant shoot length and decrease wilting, yellowing and drying of leave. Vermicompost has a high potential to control FWT (Fusarium wilt of tomato) caused by the fungal pathogen *Fusarium oxysporum f.sp. lycopersici*. It increases beneficial microbes that promote growth of plant and suppress hazardous microbes (Zhao et al. 2019; Aslam et al. 2023). In our study Vermicompost alone and in combination with others give significant results in reducing wilting and promoting growth, we found that T6 (Vermicompost), T14 (Humic acid + Vermicompost), T15 (Poultry manure + Vermicompost), T16 (Water + Vermi-compost), T17 (Carbendazim + Vermi-compost), T18 (*Trichoderma harzianum* + Vermi-compost), T19 (Humic acid + Carbendazim + *Trichoderma harzianum* + Vermicompost), T20 (Poultry manure + Carbendazim + *Trichoderma harzianum* + Vermicompost), T21 (Water + Carbendazim + *Trichoderma harzianum* + Vermicompost) reduced wilting 69, 73, 74, 72, 84, 74, 79, 78, and 78% respectively and all these treatments promote the number of flowers, fruits, branches, leaves and promote plant shoot length and decrease wilting, yellowing and drying of leaves.

5. CONCLUSION

The T17 (Carbendazim + Vermicompost) show highest wilt reducing power that is 84% than all other treatments and T3 (Water) show low wilt reducing power that is 51%. Plants treated with T17 (Carbendazim + Vermi-compost) show wilting 16% that is lowest than all other and plants treated with T3 (Water) show wilting

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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49% that is highest than all other. Wilting in T17 treated plants and all other treatments meaningfully lower than that of the control untreated plants and T3 treated plants.

Author's Contribution

Rukhsana Nazir performed the experiment and wrote original draft, Saad Aziz Ajmal, and Muhammad Bilawal Junaid conducted the data analysis, Syeda Sana Fatima designed the experiment, and Muhammad Wahab and Aqsa Arif helped in editing and proofreading.

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