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Environment conscious control of *Fusarium oxysporum* f. sp. *lycopersici*-induced tomato wilt using bio agents, phytochemicals and their combination in marked contrast to chemical

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Abstract
Tomato (*Lycopersicon esculentum*) is one of the most significant vegetable crops cultivated in 4.5 million hectares with an output of 115.5 million metric tonnes globally. India ranked third internationally in terms of output and area with production of 333.25 metric tonnes from an area of 27.56 million hectares. Several diseases limit the output of tomatoes leading to 100 percent yield losses. Among all diseases, wilt caused by *Fusarium oxysporum* f. sp. *lycopersici* (FOL) is the most destructing in both greenhouse and field environments. Hence, a study was carried out at during *Rabi* seasons in 2020-2022 at Laboratory and Agriculture Farm, School of Agriculture Science and Technology, Sangam University Bhilwara for eco-friendly management of wilt by treatment of bio-agents, botanicals and were compared to the chemical and control. The treatments were T_1 - *T. viride* @ 5%, T_2 - *T. harzianum* @ 5%, T_3 - Garlic extract @ 5%, T_4- Neem @ 5%, T_5 – NSKE @ 5%, T_6 - Karanj oil @ 5%, T_7 - *T. viride* @ 2.5% + Garlic extract @ 2.5%, T_8 - *T. harzianum* @ 2.5% + Garlic extract @ 2.5%, T_9 - *T. viride* @ 2.5% + Neem oil @ 2.5%, T_{10} - *T. harzianum* @ 2.5% + Neem oil @ 2.5%, T_{11} - *T. viride* @ 2.5% + NSKE @ 2.5%, T_{12} - *T. harzianum* @ 2.5% + NSKE @ 2.5%, T_{13} - Provax [carboxin + Thiram] @ 2gm/litre and T_{14} – Control. Results showed that Provax [carboxin + Thiram] @ 2gm/litre was best effective for attaining the maximum height (76.95 cm), maximum number of branches (15.68), maximum number of leaves (97.61) and maximum yield (219.98 q/hec.) with maximum disease reduction (8.14%). In comparison to chemical treatment bio-agent *T. harzianum* @ 5% was also equally effective for maximum height (747.32 cm), maximum number of branches (15.19), maximum number of leaves (96.52) and maximum yield (214.09 q/hec.) with maximum disease reduction (10.45%). In the lab experiment, T_1 - *T. viride* (65.64 %) followed by T_{11} - *T. harzianum* (66.11 %) was best effective in inhibiting the mycelial growth of *Fusarium oxysporum* f. sp. *lycopersici* at 24, 48, 72 and 96 hours after inoculation.

Keywords: Tomato, *Fusarium oxysporum* f. sp. *lycopersici*, eco-friendly, bio-agents, botanicals

Introduction
Tomato (*Solanum lycopersicum* L.) is a significant vegetable crop that is grown in practically all over India. Its widespread use, high nutritional content, and nutritional significance as a source of vitamins A and C all contribute to its appeal. It is cultivated in 4.5 million hectares with an output of 115.5 million metric tonnes globally. Tomato is economically desirable crop with a short growing duration with high production but the cost of cultivation is rising daily. India ranked third internationally in terms of output and area, only after sweet potatoes and potatoes (Naika *et al*, 2005) [12], with production of 333.25 metric tonnes in 2020–21 from an area of 27.56 million hectares. The average global crop loss caused by all diseases combined was about 12.8% of crop yield, whereas the tomato alone saw a loss of 21.8 percent (Anonymous, TSFAO 2020) [3]. The wilt brought on by species of *Fusarium* continues to pose a difficult management challenge among these pathogenic fungi, in particular. *Fusarium oxysporum f. sp. lycopersici*, causes Fusarium wilt of tomato, results in a significant financial loss *Fusarium* sp. induce a vast array of diseases on an astounding range of host plants. The fungus can be found in every part of the plant, from the deepest root to the highest flower and it can spread by the air, the soil or plant waste (Singha *et al*. 2011) [16]. Wilt disease, which is brought on by the *Fusarium oxysporum* species and its several unique former species, affects more than 150 hosts (Bertoldo et al. 2015) [6]. It was indicated in papers (Asha *et al*. *2011* [4]; Nirmaladevi and Srinivas 2012) [13] that *Fusarium oxysporum* existed. f. sp. *lycopersici* (Sacc.) WC Snyder and HN Hansen (FOL), a tomato disease that produces

vascular wilt, was the culprit behind the most severe yield drop (Asha *et al. 2011)* [4]. Numerous researchers are looking into various plant extracts' and essential oils' having antifungal and antibacterial qualities (Boulenouar *et al.* 2009 [7], Pizana *et al.* 2010 [14]). *Trichoderma* species, which are antagonistic to *Fusarium* species, are frequently used (El-Rafai *et al.* 2003 [8], Ahmed 2011 [1], Hend and Perveen 2012) [10]. However, it is also stated that not all isolates of *Trichoderma* spp. are equally effective at containing the pathogen in both *in vitro* and *in vivo* experiments (Ramezani 2008) [15]. As a result, the goal of the current study was to assess the effectiveness of botanicals, bio-control agents and their combinations in the management of Fusarium wilt of tomato in both *in vitro* and field conditions.

Materials and Methods

The present studies were conducted during *Rabi* season in the central field and research laboratory, School of Agriculture Science and Technology, Plant Pathology lab, Sangam University Bhilwara, Rajasthan, during the year 2020-21 and 2021-22. The field experiment was conducted using Randomized block design (RBD) and *in vitro* experiment using complete randomized design (CRD).

In the present study, 42 plots were inoculated regularly with Inoculum (5g. / Kg of soil) to build the conidia inoculum potential of *Fusarium oxysporum* f. sp. *lycopersici* having C.F.U. of 2-3 X 107 except control as un-inoculated. Thereafter, healthy seedlings of tomato variety Pusa Rubey, disinfected with 2.5% Sodium hypo-chloride solution were sown 15 seedlings per plot were treated with the treatments for an hour. The treatments were T_1 - *T. viride* @ 5%, T_2 - *T. harzianum* @ 5%, T_3 - Garlic extract @ 5%, T_4- Neem @ 5%, T_5 – NSKE @ 5%, T_6 - Karanj oil @ 5%, T_7 - *T. viride* @ 2.5% + Garlic extract @ 2.5%, T_8 - *T. harzianum*@ 2.5% + Garlic extract @ 2.5%, T_9 - *T. viride* @ 2.5% + Neem oil @ 2.5%, T_{10} - *T. harzianum* @ 2.5% + Neem oil @ 2.5%, T_{11} - *T. viride* @ 2.5% + NSKE @ 2.5%, T_{12} - *T. harzianum*@ 2.5% + NSKE @ 2.5%, T_{13} - Provax [carboxin + Thiram] @ 2gm/litre and T_{14} – Control.

After treatment, the seedlings were sown at the depth of 2-3 cm such that plant population in a plot was maintained to 10 plants per plot. The wilted plants for each isolate were counted at 30, 60 and 90 DAT to record the effects on plant height, number of branches, number of leaves, yield and wilt incidence percent.

Results and Discussion

Results revealed that maximum plant height was recorded at 30, 60 and 90 DAT where treatment T_{13} - Provax [carboxin + Thiram] @ 2gm/liter (76.950) and T_2- *T. harzianum @ 5%* (74.316) followed by T_1- *T. viride* @ 5% (72.350), T_{11}- *T. viride* @ 2.5% + NSKE @ 2.5% (71.216), T_{12}- *T. harzianum@ 2.5% + NSKE @ 2.5%* (69.250), T_5- *NSKE @ 5%* (68.600), T_{10}- *T. harzianum* @ 2.5% + Neem oil @ 2.5% (68.333), T_9- *T. viride* @ 2.5% + Neem oil @ 2.5% (66.450), T_7- T. viride @ 2.5% + Garlic extract @ 2.5% (62.666), T_8- *T. harzianum* @ 2.5% + Garlic extract @ 2.5% (62.016), T_4- Neem oil @ 5% (60.833), T_3- Garlic extract @ 5% (59.666), T6- Karanj oil @ 5% (59.283) and lowest plant height was recorded in T_{14}- Control (58.533).

It was also noticed that maximum number of branches were recorded in treatment T_{13} - Provax [carboxin + Thiram] @ 2gm/liter (15.680) and T_2- *T. harzianum @ 5%* (15.186) followed by T_1- *T. viride @ 5%* (13.926), T_{11}- *T. viride* @ 2.5% + NSKE @ 2.5% (12.870), T_{12}- *T. harzianum* @ 2.5% + NSKE @ 2.5% (12.380), T_5- NSKE @ 5% (11.843), T_{10}- *T. harzianum* @ 2.5% + Neem oil @ 2.5% (11.546), T_9- *T. viride* @ 2.5% + Neem oil @ 2.5% (11.290), T_7- *T. viride* @ 2.5% + Garlic extract @ 2.5% (11.073), T_8- *T. harzianum* @ 2.5% + Garlic extract @ 2.5% (10.750), T_4- Neem oil @ 5% (10.576), T_3- Garlic extract @ 5% (8.646), T_6- Karanj oil @ 5% (7.870) and lowest plant height was recorded in T_{14}- Control (7.320).

Maximum number of leaves were recorded in treatment T_{13} - Provax [carboxin + Thiram] @ 2gm/litre (97.610) and T_2- *T. harzianum @ 5%* (96.516) followed by T_1- *T. viride @ 5%* (93.365), T_{11}- T. viride @ 2.5% + NSKE @ 2.5% (92.240), T_{12}- *T. harzianum @ 2.5%* + NSKE @ 2.5% (90.725), T_5- NSKE @ 5% (89.610), T_{10}- *T. harzianum* @ 2.5% + Neem oil @ 2.5% (88.580), T_9- T. viride @ 2.5% + Neem oil @ 2.5% (85.565), T_7- *T. viride* @ 2.5% + Garlic extract @ 2.5% (83.135), T_8- *T. harzianum*@ 2.5% + Garlic extract @ 2.5% (80.733), T_4- Neem oil @ 5% (78.436), T_3- Garlic extract @ 5% (78.736), T_6- Karanj oil @ 5% (75.796) and lowest number of leaves was recorded in T_{14}- Control (74.063).

Lowest wilt incidence was recorded in treatment T_{13} - Provax [carboxin + Thiram] @ 2gm/liter (8.143) and T_2- *T. harzianum @ 5%* (10.446) followed by T_1- *T. viride @ 5%* (12.556), T_{11}- *T. viride* @ 2.5% + NSKE @ 2.5% (14.623), T_{12}- *T. harzianum @ 2.5% + NSKE @ 2.5%* (15.856), T_5- *NSKE @ 5%* (16.755), T_{10}- *T. harzianum* @ 2.5% + Neem oil @ 2.5% (17.543), T_9- *T. viride* @ 2.5% + Neem oil @ 2.5% (19.780), T_7- T. viride @ 2.5% + Garlic extract @ 2.5% (22.110), T_8- *T. harzianum* @ 2.5% + Garlic extract @ 2.5% (27.266), T_4- Neem oil @ 5% (30.726), T_3- Garlic extract @ 5% (34.413), T6- Karanj oil @ 5% (37.026) and maximum wilt incidence was recorded in T_{14}- Control (39.986).

Yield (q/ hec.) calculated on the basis of yield per plot and it was observed that maximum yield (q/h.) was recorded in treatment T_{13} - Provax [carboxin + Thiram] @ 2gm/litre (219.983) and T_2- *T. harzianum @ 5%* (214.090) followed by T_1- *T. viride @ 5%* (203.260), T_{11}- *T. viride* @ 2.5% + NSKE @ 2.5% (180.130), T_{12}- *T. harzianum@ 2.5%* + NSKE @ 2.5% (170.350), T_5- NSKE @ 5% (167.130), T_{10}- *T. harzianum* @ 2.5% + Neem oil @ 2.5% (135.480), T_9- *T. viride* @ 2.5% + Neem oil @ 2.5% (124.873), T_7- *T. viride* @ 2.5% + Garlic extract @ 2.5% (107.906), T_8- *T. harzianum@* 2.5% + Garlic extract @ 2.5% (93.890), T_4- Neem oil @ 5% (83.946), T_3- Garlic extract @ 5% (68.610), T6- Karanj oil @ 5% (58.280) and minimum yield (q/h.) was recorded in T_{14}- Control (34.463).

In vitro experiment showed that maximum inhibition was recorded for T_1 - *T. viride* @ 5% (65.64), T_{11} - *T. viride* @ 2.5% + NSKE @ 2.5% (65.64), T_{12}- *T. harzianum@* 2.5% + NSKE @ 2.5% (61.43), T_{10} - *T. harzianum* @ 2.5% + Neem oil @ 2.5% (59.79), T_9 - *T. viride* @ 2.5% + Neem oil @ 2.5% (57.69), T_7 - *T. viride* @ 2.5% + Garlic extract @ 2.5% (55.59), T_8 - *T. harzianum@* 2.5% + Garlic extract @ 2.5% (55.35), T_6 - Karanj oil @ 5% (55.12), T_4 - Neem oil @ 5% (54.42), T_{13} - Provax [carboxin + Thiram] @ 2 % (54.18), T_5 - NSKE @ 5% (54.18), T_3 - Garlic extract @ 5% (53.95) and T_{14} – Control (0).

From the above field study, it can be clearly observed that treatments T_{13} - Provax [carboxin + Thiram] @ 2gm/litre and T_2- *T. harzianum* @ 5% were best effective with respect to increment in plant growth parameters, yield and reducing the

wilt incidence. It is observed that chemical treatment is affective but bio-agent had the equivalent effects which were similar to studies taken up by Alwathnani and Perveen (2011) where they reported that plants treated with *T. harzianum* (44.4%) showed the greatest control of the wilt disease. Also, Sundaramoorthy and Balabaskar (2013) studied the Fusarium wilt and reported that *Trichoderma* species to promote the growth and yield parameters of in vitro and in vivo conditions. Barari (2015) [5] reported that natural isolates of *Trichoderma* species were effective in promoting tomato growth and yield characteristics as well as controlling the Fusarium wilt disease in both *in vitro* and *in vivo* conditions.

In the *in vitro* studies, T_2 - *T. harzianum* (66.11 %) followed by T_1 - *T. viride* (65.64%) was best effective in inhibiting the mycelial growth of *Fusarium oxysporum* f. sp. *lycopersici* which shows that bio-agents are best for limiting the pathogen in lab conditions similar to Ghorbandi, *et al.* (2016) [9] where they studied the impact of bio-agents, plants, and fungicide against *Fusarium oxysporum*. The bio agent (*Trichoderma harzianum*) and leaf extracts' inhibition and action against the studied pathogen was brought on by competition and by halting the pathogen's mycelia growth, which is extremely beneficial and safe for the environment, animals, and human health. Also, Houssien *et al.* (2010) [11] concluded from an experiment that using *Trichoderma harzianum*, salicylic acid, and a low dose of the fungicide thiophanate methyl improved tomato defence against the wilt disease caused by *Fusarium oxysporum* f. sp. *lycopersici* in greenhouse settings.

Table 1: Effect of bio-agents, botanicals and their combinations on plant height (cm.) of tomato at 30, 60 and 90 DAT

Treatments	30 DAT	60 DAT	90 DAT
T_1 *T. viride* @ 5%	36.633^{abc}	52.716^{b}	72.350^{bc}
T_2 *T. harzianum* @ 5%	37.416^{ab}	54.483^{a}	74.316^{b}
T_3 Garlic extract @ 5%	25.450^{hi}	41.250^{gh}	59.666^{h}
T_4 Neem oil @ 5%	26.366^{h}	42.583^{g}	60.833^{gh}
T_5 NSKE @ 5%	34.316^{de}	49.150^{c}	68.600^{ef}
T_6 Karanj oil @ 5%	24.466^{i}	40.100^{h}	59.283^{h}
T_7 *T. viride* @ 2.5% + Garlic extract @ 2.5%	31.100^{f}	46.366^{e}	62.666^{g}
T_8 *T. harzianum*@ 2.5% + Garlic extract @ 2.5%	28.766^{g}	44.300^{f}	62.016^{g}
T_9 *T. viride* @ 2.5% + Neem oil @ 2.5%	32.650^{ef}	47.216^{de}	66.450^{f}
T_{10} *T. harzianum* @ 2.5% + Neem oil @ 2.5%	33.366^{de}	48.750^{cd}	68.333^{ef}
T_{11} *T. viride* @ 2.5% + NSKE @ 2.5%	36.300^{bc}	52.166^{b}	71.216^{cd}
T_{12} *T. harzianum*@ 2.5% + NSKE @ 2.5%	35.066^{cd}	50.233^{c}	69.250^{de}
T_{13} Provax [carboxin+Thiram] @ 2gm/litre	38.433^{a}	56.166^{a}	76.950^{a}
T_{14} Control	20.683^{j}	39.650^{h}	58.533
S Ed (±)	0.908	0.825	1.125
C. D. (0.05)	1.86	1.696	2.314

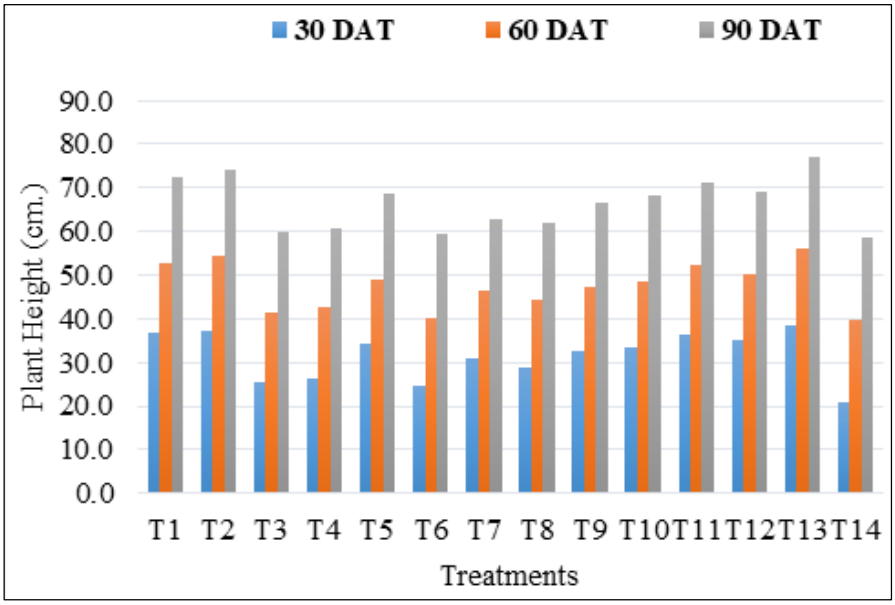

Fig 1: Effect of bio-agents, botanicals and their combinations on plant height (cm.) of tomato at 30, 60 and 90 DAT

Table 2: Effect of bio-agents, botanicals and their combinations on number of branches in tomato at 30, 60 and 90 DAT

Treatments	30 DAT	60 DAT	90 DAT
T_1 *T. viride* @ 5%	7.396^{b}	11.080^{c}	13.926^{c}
T_2 *T. harzianum* @ 5%	9.330^{a}	12.446^{b}	15.186^{b}
T_3 Garlic extract @ 5%	2.850^{g}	5.500^{i}	8.646^{l}
T_4 Neem oil @ 5%	2.943^{g}	6.146^{h}	10.576^{k}
T_5 NSKE @ 5%	4.600^{e}	8.746^{e}	11.843^{f}
T_6 Karanj oil @ 5%	2.283^{h}	4.550^{j}	7.870^{m}
T_7 *T. viride* @ 2.5% + Garlic extract @ 2.5%	3.370^{f}	7.080^{g}	11.073^{i}
T_8 *T. harzianum*@ 2.5% + Garlic extract @ 2.5%	3.153^{fg}	6.940^{g}	10.750^{j}
T_9 *T. viride* @ 2.5% + Neem oil @ 2.5%	3.463^{f}	7.650^{f}	11.290^{h}
T_{10} *T. harzianum* @ 2.5% + Neem oil @ 2.5%	3.503^{f}	7.766^{f}	11.546^{g}
T_{11} *T. viride* @ 2.5% + NSKE @ 2.5%	6.596^{c}	10.270^{d}	12.870^{d}
T_{12} *T. harzianum*@ 2.5% + NSKE @ 2.5%	5.530^{d}	9.060^{e}	12.380^{e}
T_{13} Provax [carboxin+Thiram] @ 2gm/litre	9.670^{a}	12.873a	15.680^{a}
T_{14} Control	1.470^{i}	3.743^{k}	7.320^{n}
S Ed (±)	0.211	0.183	0.037
C. D. (0.05)	0.423	0.381	0.101

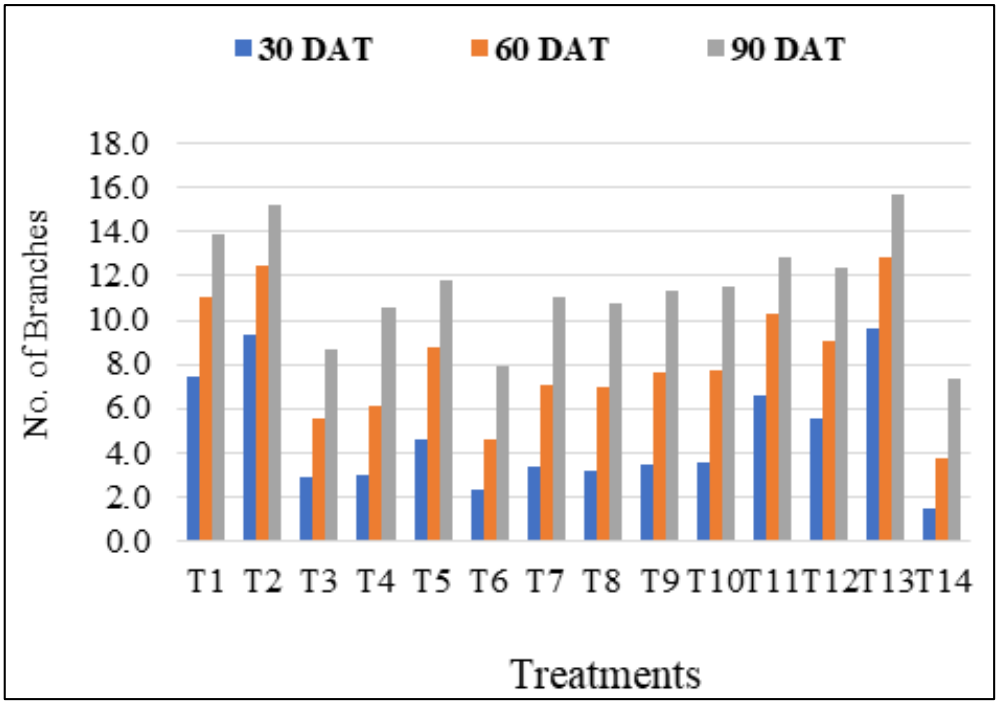

Fig 2: Effect of bio-agents, botanicals and their combinations on number of branches in tomato at 30, 60 and 90 DAT

Table 3: Effect of bio-agents, botanicals and their combinations on number of leaves in tomato at 30, 60 and 90 DAT

Treatments	30 DAT	60 DAT	90 DAT
T_1 *T. viride* @ 5%	54.373^{b}	67.706^{c}	93.365^{b}
T_2 *T. harzianum* @ 5%	55.703^{b}	70.515^{b}	96.516^{a}
T_3 Garlic extract @ 5%	35.880^{i}	52.176^{j}	78.736^{h}
T_4 Neem oil @ 5%	38.243^{h}	54.776^{i}	79.436^{h}
T_5 NSKE @ 5%	48.480^{d}	62.573^{f}	89.610^{cd}
T_6 Karanj oil @ 5%	35.336^{i}	49.606^{k}	75.796^{i}
T_7 *T. viride* @ 2.5% + Garlic extract @ 2.5%	43.466^{f}	57.753^{h}	83.135^{f}
T_8 *T. harzianum*@ 2.5% + Garlic extract @ 2.5%	40.146^{g}	55.670^{i}	80.733^{g}
T_9 *T. viride* @ 2.5% + Neem oil @ 2.5%	45.823^{e}	60.326^{g}	85.565^{e}
T_{10} *T. harzianum* @ 2.5% + Neem oil @ 2.5%	46.820^{e}	61.693^{f}	88.580^{d}
T_{11} *T. viride* @ 2.5% + NSKE @ 2.5%	50.875^{c}	65.766^{d}	92.240^{b}
T_{12} *T. harzianu m*@ 2.5% + NSKE @ 2.5%	49.376^{cd}	64.543^{e}	90.725^{c}
T_{13} Provax [carboxin+Thiram] @ 2gm/liter	58.776^{a}	75.886^{a}	97.610^{a}
T_{14} Control	28.446^{j}	48.723^{k}	74.063^{j}
S Ed (±)	0.744	0.559	0.607
C. D. (0.05)	1.533	1.166	1.245

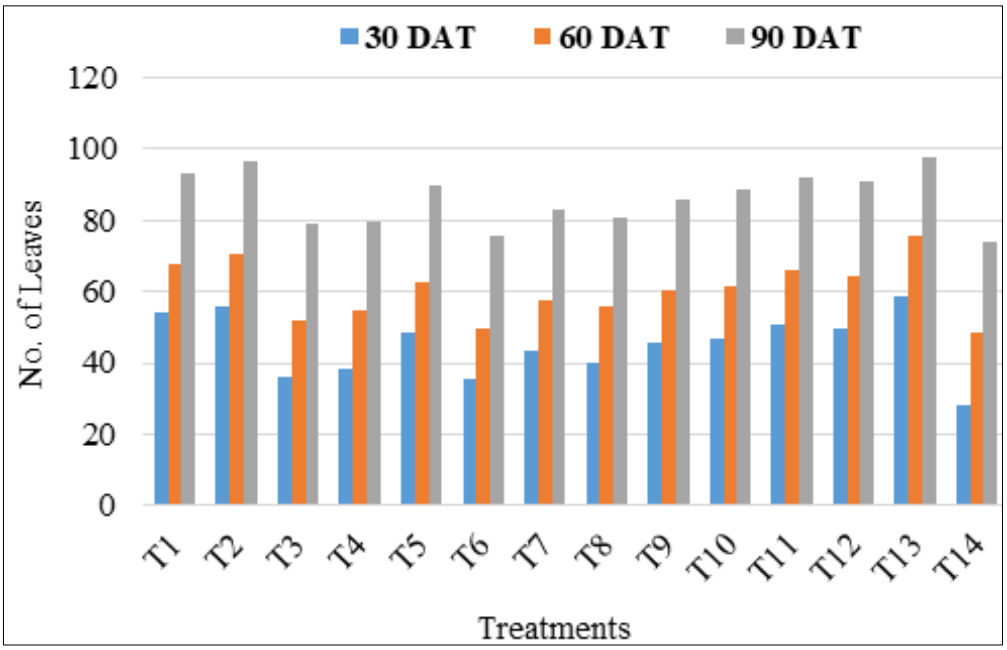

Fig 3: Effect of bio-agents, botanicals and their combinations on number of leaves in tomato at 30, 60 and 90 DAT

Table 4: Effect of bio-agents, botanicals and their combinations on disease incidence percent in tomato at 30, 60 and 90 DAT

Treatments	30 DAT	60 DAT	90 DAT
T_1 *T. viride* @ 5%	2.213^{fg}	9.783^{hij}	12.556^{gh}
T_2 *T. harzianum* @ 5%	0.600^{fg}	8.925^{ij}	10.446^{hi}
T_3 Garlic extract @ 5%	12.476^{b}	30.360^{b}	34.413^{b}
T_4 Neem oil @ 5%	10.283^{c}	27.685^{b}	30.726^{c}
T_5 NSKE @ 5%	2.525^{ef}	14.873^{fg}	16.755^{ef}
T_6 Karanj oil @ 5%	15.403^{a}	34.483^{a}	37.026^{ab}
T_7 *T. viride* @ 2.5% + Garlic extract @ 2.5%	9.565^{c}	19.595^{d}	22.110^{d}
T_8 *T. harzianum*@ 2.5% + Garlic extract @ 2.5%	9.680^{c}	24.303^{c}	27.266^{c}
T_9 *T. viride* @ 2.5% + Neem oil @ 2.5%	6.626^{d}	18.565^{de}	19.780^{de}
T_{10} *T. harzianum* @ 2.5% + Neem oil @ 2.5%	4.430^{e}	16.333^{ef}	17.543^{ef}
T_{11} *T. viride* @ 2.5% + NSKE @ 2.5%	2.316^{fg}	10.995^{hi}	14.623^{fg}
T_{12} *T. harzianum*@ 2.5% + NSKE @ 2.5%	2.425^{fg}	12.743^{gh}	15.856^{fg}
T_{13} Provax [carboxin+Thiram] @ 2gm/litre	0.535^{g}	7.906^{j}	8.143^{i}
T_{14} Control	16.786^{a}	37.055^{a}	39.986^{a}
S Ed (±)	0.943	1.449	1.798
C. D. (0.05)	1.944	2.989	3.690

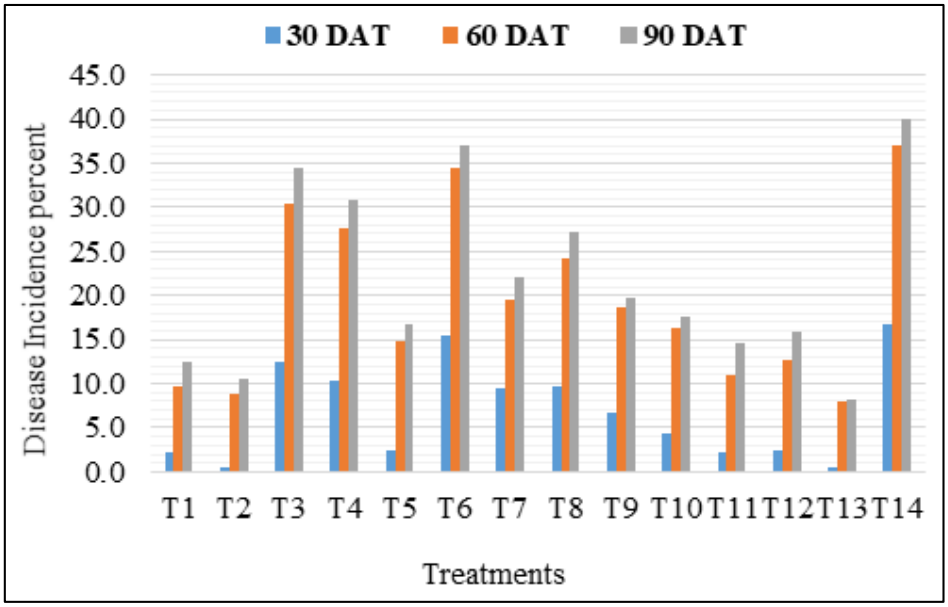

Fig 4: Effect of bio-agents, botanicals and their combinations on disease incidence percent in tomato at 30, 60 and 90 DAT

Table 5: Effect of bio-agents, botanicals and their combinations on yield (kg/plot and q/hec.) of tomato

Treatments	kg / plot	q/ ha
T_1 *T. viride* @ 5%	18.293[b]	203.260[b]
T_2 *T. harzianum* @ 5%	19.270[a]	214.090[a]
T_3 Garlic extract @ 5%	6.176[j]	68.610[j]
T_4 Neem oil @ 5%	7.556[i]	83.946[i]
T_5 NSKE @ 5%	15.046[d]	167.130[d]
T_6 Karanj oil @ 5%	5.250[k]	58.280[k]
T_7 *T. viride* @ 2.5% + Garlic extract @ 2.5%	9.713[g]	107.906[g]
T_8 *T. harzianum*@ 2.5% + Garlic extract @ 2.5%	8.450[h]	93.890[h]
T_9 *T. viride* @ 2.5% + Neem oil @ 2.5%	11.243[f]	124.873[f]
T_{10} *T. harzianum* @ 2.5% + Neem oil @ 2.5%	12.196[e]	135.480[e]
T_{11} *T. viride* @ 2.5% + NSKE @ 2.5%	16.216[c]	180.130[c]
T_{12} *T. harzianum*@ 2.5% + NSKE @ 2.5%	15.333[d]	170.350[d]
T_{13} Provax [carboxin+Thiram] @ 2gm/litre	19.803[a]	219.983[a]
T_{14} Control	3.106[l]	34.463[l]
S Ed (±)	0.392	4.353
C. D. (0.05)	0.802	8.951

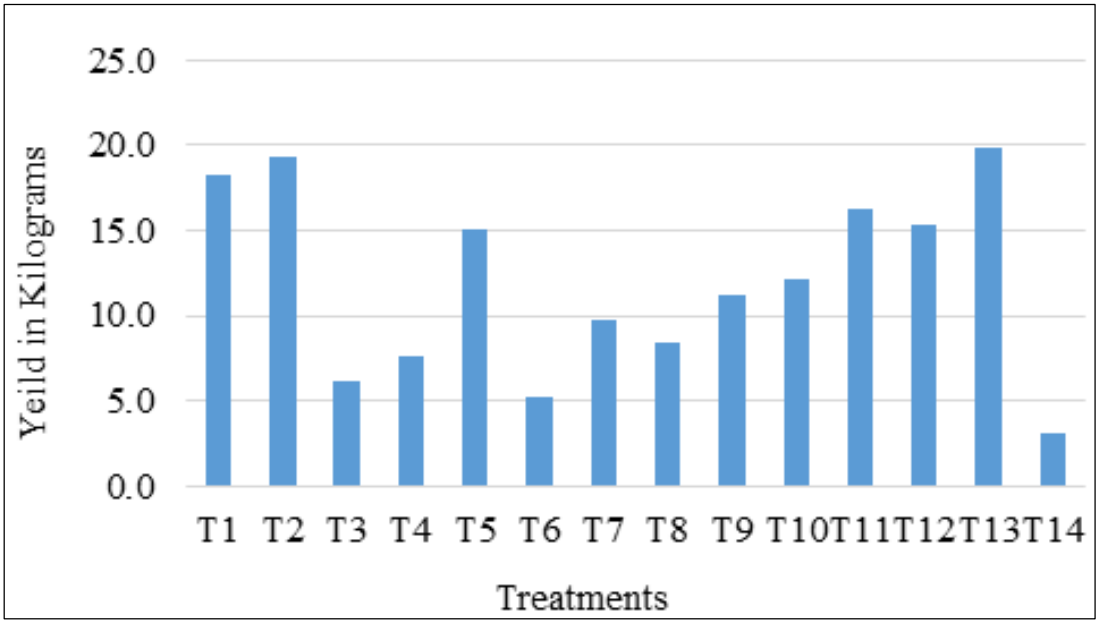

Fig 5: Effect of bio-agents, botanicals and their combinations on yield (kg/plot) of tomato

Table 6: *In vitro* management of the tomato wilt (*Fusarium oxysporum* f. sp. *lycopersici*) by bio-agents, botanicals and their combinations in comparison to chemical at 24, 48, 72 and 96 hours after inoculation

Treatments	24 hrs	48 hrs	72 hrs	96 hrs
T_1	38.05	42.16	55.89	65.64
T_2	43.95	57.71	60.27	66.11
T_3	7.08	14.18	40.74	53.95
T_4	10.03	26.00	46.46	54.42
T_5	7.08	21.64	43.10	54.18
T_6	11.50	26.00	47.14	55.12
T_7	15.93	28.48	48.15	55.59
T_8	14.45	27.24	48.15	55.35
T_9	17.40	29.10	49.16	57.69
T_{10}	20.35	35.95	53.20	59.79
T_{11}	27.73	39.68	55.89	65.64
T_{12}	23.30	37.81	53.54	61.43
T_{13}	8.55	24.75	43.77	54.18
T_{14}	0.00	0.00	0.00	0.00
S. Ed (±)	0.068	0.157	0.155	0.205
C. D. (0.05)	0.162	0.302	0.309	0.438

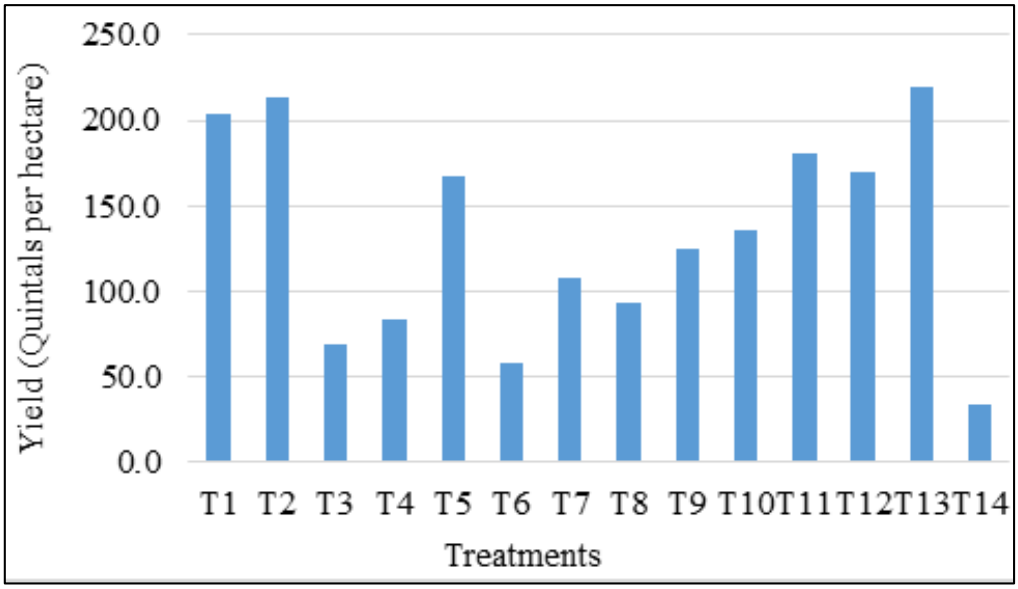

Fig 6: Effect of bio-agents, botanicals and their combinations on yield (q/hec.) of tomato

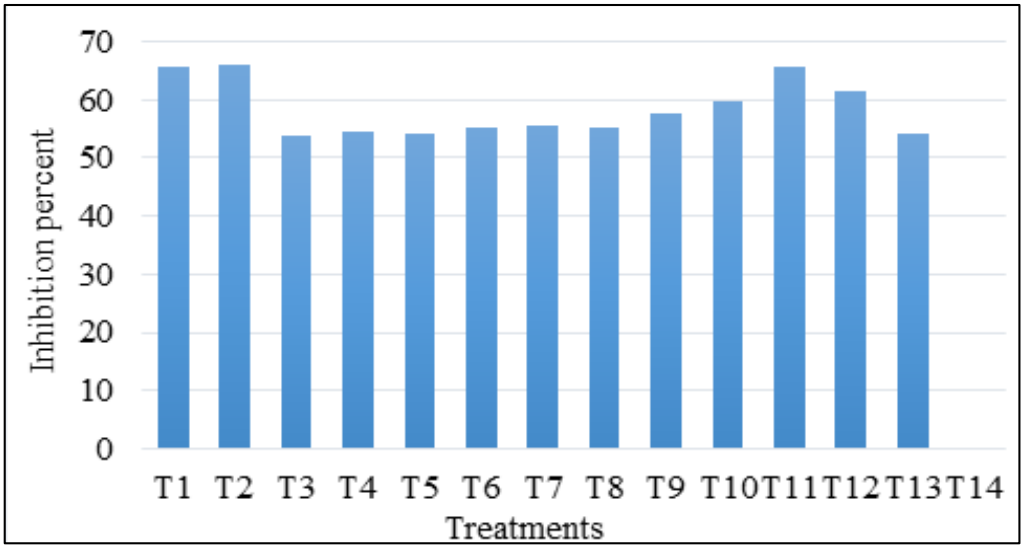

Fig 7: *In vitro* management of the tomato wilt (*Fusarium oxysporum* f. sp. *lycopersici*) by bio-agents, botanicals and their combinations in comparison to chemical at 24, 48, 72 and 96 hours after inoculation

Conclusion

Studies on the eco-friendly management of wilt disease with bio-agents, botanicals and their combinations in comparison to chemicals revealed that chemical treatment of Provax [carboxin + Thiram] @ 2gm/litre as seedling dip treatment was best suited practice followed by *T. harzianum* @ 5% for effective management of wilt disease of tomato and enhanced growth. *In vitro* study of wilt disease with bio-agents, botanicals and their combinations in comparison to chemicals reveal that bio-agent *T. viride* and *T. harzianum* were best effective in reducing mycelial growth of *Fusarium oxysporum* f. sp. *lycopersici*. Hence, based on the above studies it can be concluded that bio-agents are better in comparison to chemical treatment. It neither pollutes nor harms the non-targeted organisms. Therefore, Farmers are strongly recommended to use bio-formulations for the management of wilt disease in tomatoes.

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