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BIOFUMIGATION: AN ECO-FRIENDLY APPROACH FOR THE MANAGEMENT OF WILT DISEASE OF TOMATO CAUSED BY *Fusarium oxysporum* F. SP. *Lycopersici*

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ABSTRACT

Tomatoes are considered one of the world's most popular vegetable crops, widely grown throughout the world. Its production is, however, challenged by various constraints, among which pests and diseases are very prominent. Fungal wilt of tomato is considered one of the most severe diseases affecting tomato, reducing yield in both field and greenhouse conditions. Considering the importance of the disease, the present investigation was undertaken to evaluate the most effective rate of brassica crop as a biofumigant for eco-friendly and sustainable management of fungal wilt of tomatoes under pot conditions. The experiment was carried out in CRD with 6 treatments and 3 replications. The lowest disease incidence (0%) was observed in the pot incorporated with TS-38 @ 18 kg per ha and 16 kg per ha, followed by disease incidence of (41.76 %, 48.25 %) with seed rate of 14 kg per ha and 12 kg per ha, respectively. The incorporation of TS-38 @ 18 kg per ha and 16 kg per ha recorded the highest reduction of disease incidence (100%) over control, followed by 14kg per ha and 12 kg per ha with 46.63% and 38.33 % reduction of disease incidence, respectively. The pot incorporated with TS-38 @ 10 kg per ha was found to be the least effective, exhibiting the lowest reduction (30.04 %) of disease incidence over the control. The lowest microbial population (10.33×10^{-6} CFU g^{-1} of soil) was recorded in pot incorporated with TS-38 @ 18 kg per ha followed by 16 kg per ha with a microbial population of (10.66×10^{-6} CFU g^{-1} of soil) whereas, the highest microbial population (13.00×10^{-6} CFU g^{-1} of soil) was recorded in pot incorporated with TS-38 @ 10 kg per ha.

Keywords **:** Fungal wilt, Brassica crops, biofumigant, Disease Incidence, CFU

Introduction

Tomato (*Lycopersicon esculentum* L.) is one of the most important vegetable crops in the world. It originated in western South America. It is an important source of umami flavour, "fifth taste" (Fleming, 2013). Tomato is a widely cultivated vegetable crop and a significant part of different cuisines around the world. It is a good source of income for small and marginal farmers (Parmar *et al*., 2019).

India is the second-largest producer of tomatoes after China. In India, it occupies an area of about 854 thousand ha, producing over 21,181,000 tonnes in 2021 and an estimated 20.34 million metric tonnes in 2022 with a productivity of 25.0 MT per hectare (Anon, 2022a). In India, Madhya Pradesh is the leading producer of tomatoes, producing 29,70,000 tonnes followed by Andhra Pradesh and Karnataka (Anon, 2022b). In Assam, tomato is cultivated over 18.28 thousand ha with a total production of 396.24 thousand MT (Anon, 2018).

Tomatoes are vulnerable to a range of biotic (fungi, bacteria, viruses) and abiotic (temperature, humidity, sunlight, malnutrition) stresses (Balanchard,

1992). *Fusarium* wilt of tomato is one of the most destructive diseases of tomatoes caused by *Fusarium oxysporum* f.sp. *lycopersici*. Tomato crop faces crop loss of up to 25-55 per cent due to fungal infections caused by *Fusarium oxysporum* worldwide (Devi *et al*., 2016), and there are reports that it may be affecting even resistant tomato varieties. In severe conditions, this disease can result in a yield loss of up to 80%.

Farmers mostly depend on commercial fungicides to manage the disease. Though some of these chemical fungicides have been observed to be effective in controlling the disease, these chemicals have been widely recognized to have adverse environmental effects, and are very expensive. Therefore, alternative solutions for the sustainable control of this important disease must be explored. Biofumigation and green manuring can play an important role in utilizing natural resources for the management of this disease.

Bio-fumigation greatly reduced pesticide application, making farming economically feasible as well as environmentally safer, as it has been reported to add organic matter to the soil, leading to increased soil aeration, water infiltration rates, and soil water holding capacity (Karavina and Mandumbu, 2012). It is a sustainable method of soil management that can increase soil organic matter, moderate soil pH, suppress weeds and soil-borne pathogens through production of glucosinolates, and increase water infiltration (Rudolph *et al*., 2015). Bio-fumigation was also reported by Balesh *et al*. (2005), to have increased soil porosity if used as a green manure and added more organic carbon to the soil, thereby increasing the activity of soil fauna and flora

Biofumigation refers to the agronomic practice of using volatile chemicals (allelochemicals) released from decomposing Brassica tissues to suppress soil-borne pests and pathogens. The most common volatile compounds produced during the breakdown of Brassicas are isothiocyanates (ITCs). Mustard produces many naturally occurring compounds such as glucosinolates (GCs), which break down as the plant decomposes into allyl-ITC, which is similar to methyl ITC, the active ingredient in the chemical fumigant Netam sodium. GCs are sulfur-containing chemicals that are produced as secondary metabolites by Brassicas.

Materials and Methods

The present experiment was carried out during 2023 at the experimental plot in Biswanath College of Agriculture (BNCA), Biswanath Chariali, under Biswanath district of Assam. The susceptible variety "Pusa Ruby" was considered for this experiment.

Isolation and Purification of the Pathogen

The disease specimens were collected from the Horticultural orchard, BNCA, Biswanath Chariali, showing typical symptoms of fungal wilt on tomato crops. The samples were brought to the laboratory for critical observation and investigation, such as symptoms, followed by isolation and further morpho-cultural studies of the pathogen. The pathogen was isolated using a tissue isolation technique (Ricker and Ricker, 1936). The fungal culture was purified by the single hyphal tip method, and also a pure fungal culture was also obtained using a single spore isolation technique (Johnston and Booth, 1983). The pure culture of the pathogen was maintained throughout the period of investigation on Potato Dextrose Agar (PDA) slants by routine sub-culturing at regular intervals and preserving at 4ºC in a refrigerator, and the culture was used when needed after restoring it to an active state by keeping it at room temperature for all subsequent studies. The pathogenicity of the pathogen causing fungal wilt of tomato was confirmed by Koch's postulates.

Identification of the Isolated Pathogen

Morphological and molecular characterization of the associated fungal isolate was carried out for the identification of the pathogen. A microscopic study of the fungal pathogen was conducted to evaluate the morphological characteristics. The pathogen was identified with the available relevant literature, a key, a monograph (Tamuro, 2013), and the CMI description. Identification of *Fusarium oxysporum* f. sp. *lycopersici* was done based on the spore morphology and colony characters of the fungus by referring to the "Illustrated genera of Imperfect fungi" (Barnett and hunter, 1972).

Evaluation of Brassicaseous crops for Biofumigation against *Fusarium oxysporum* f. sp. *lycopersici* in a Pot Experiment

The study was conducted during the rabi season of October 2023 in the Herbal Garden of Biswanath College of Agriculture, Biswanath Chariali, with six treatments and three replications to test the effect of seed rate of brassicaceous crops as biofumigant against the pathogen. The design of the experiment was a Completely Randomized Block Design (CRD).

Inoculation of Pathogen

The fungal culture was prepared in Maize Sand Medium as described by Dutta and Deb (2020), and inoculation of the pathogen was done before transplanting of tomato plant. Fifteen (15) days old MSM media with mycelium were mixed well by shaking and breaking sand clogs and applied to the pot

soil @ 5% (w/w) with sufficient inoculum of the pathogen. Control pots were also inoculated with MSM media.

Application of Biofumigants

The brassica crop, Rapeseed var. TS-38 was sown in a Thermocol box of size (40 cm x 30 cm) as per the rate mentioned in the different treatments. The brassicaceous plants were chopped after attaining the maximum vegetative growth stage and incorporated with the pot soil, and the pots were covered with a polythene sheet and kept for 30 days for decomposition.

Planting of Tomato Seedlings

Individual pots were taken for planting of tomato seedlings after 30 days of incorporation of biofumigants crops. 20-day-old tomato seedlings raised in poly treys were transplanted in the pots @ three seedlings per Thermocol pot, and all the recommended agronomical practices from the Package of Practices (POP) for horticultural crops of Assam were followed. Regular observations on the development of initial symptoms of wilt disease were made at 14 and 21days after transplanting.

Assessment of Disease Incidence

The fungal wilt incidence was assessed at 14 and 21 days after transplanting (DAT) in each Thermocol pot. The numbers of infected plants were counted, and the mean wilt incidence was expressed as a percentage. The percentage of disease incidence was calculated by using the formula given by Mayee and Datar (1986).

Disease Incidence (%) = (Number of infected plants / Total number of plants observed) ×100

Enumeration of the Total Microbial Population of Soil

Soil samples were collected from all the treatment pots before and after incorporation of bio-fumigant crop and microbial population in untreated control pots and treated pots (CFU x 10^{-6} g^{-1} soil) were enumerated by following the serial dilution technique *in vitro*. The experiment was conducted in a Completely Randomized Block Design (CRD) with five replications (Wollum, 1982).

Statistical Analysis

The experimental data collected were analysed statistically for their significance difference by the normal statistical procedure adopted for a Completely Randomized Block Design, and interpretation of data was carried out in accordance with Gomez and Gomez (1984). The observed data were analysed by the OPSTAT package of programs (Sheoran, 2006) after angular transformation. The treatment means were compared by Duncan's Multiple Range Test (DMRT).

Results

Symptomatology

The tomato plants grown in the Thermocol pot exhibited various symptoms of fungal wilt during the course of the present investigation. Infected plants exhibited light vein clearing of young leaves and yellowing of the lower leaves, followed by leaf dropping. Browning of vascular tissue was observed in severe wilting. Initially, leaf yellowing was observed on one side of the plant, and later, the death of the entire plant occurred. When the infected stem was sliced open, vascular discolouration or brown streaks were visible.

Isolation and Purification of the Pathogen

Tomato plants showing typical symptoms of fungal wilt were collected from the Horticultural Orchard, BNCA, Biswanath Chariali, AAU, for isolation of the pathogen. The isolated fungus was purified by following the hyphal tip method and maintained on PDA slants for future research work.

Identification of the Isolated Pathogen

In culture, the colony of the fungus appears cottony white in colour,–gradually turning pink in colour, and in later stages reverse view of the culture turned reddish in colour. Conidial masses were observed in the cottony portion of the culture, which were oval to kidney-shaped, tapering, and septate in three cells. Conidia were hyaline, oval to kidney-shaped, measuring 15.00 to 20.00 µm in length and 4-7 µm in width. Chlamydospores formed in chains. Oval to kidney-shaped microconidia have false heads on short monophialides, and macroconidia are sickle-shaped, thin-walled, and delicate. Fungal isolate was identified as *Fusarium oxysporum* f.sp.*lycopersici* after comparing with standard literature and by referring to the "Illustrated genera of Imperfect fungi" (Barnett and Hunter, 1972).

Pathogenicity Test

The pathogenicity of the pathogen causing fungal wilt of tomato was confirmed by Koch's postulates. Garden soil was first sterilized in an autoclave at 15 lbs pressure, 121°C for two successive days. Earthen pots were filled with five kg of sterilized soil and inoculated by mixing the freshly prepared *Fusarium* inoculum (multiplied on sand maize medium) @ 50g/kg soil (Muthusamy,1972). Tomato seedlings were planted in a pot and maintained properly by regular watering, and constantly observed for the development of symptoms.

The tomato plants exhibited typical fungal wilt symptoms, and the fungus was again isolated from the infected plant, purified, and maintained in PDA slants. The fungus reproduced a similar kind of cultural characteristic.

Effect of seed rate of biofumigant crop (Rapeseed var.TS-38) on wilt of tomato plants

The rapeseed variety TS-38 was found to be significant in reducing the incidence of fungal wilt of tomato in all the seed rates, *viz.*, 10 kg, 12 kg, 14 kg, 16 kg, and 18 kg per ha, which resulted in a fresh biomass of 21.87, 22.72, 23.68, 24.69, and 25.69 tonnes, respectively.

Data presented in Table 1 revealed that the lowest disease incidence (0%) was observed in T_4 and T_5 with a seed rate of 16 kg per ha (24.69 tonnes fresh biomass) and 18kg per ha (25.69 tonnes fresh biomass), respectively. The highest disease incidence (54.74 %) was observed in T_1 with a seed rate of 10 kg/ha (21.87 tonnes). In regards to reduction of disease incidence (DI) over control, the pot with seed rate of 16 kg and 18 kg TS-38 per ha yielding 24.69 and 25.69 tonnes fresh biomass resulted highest reduction (100%) of disease incidence over control followed by 14 kg (23.68 tonnes fresh biomass) and 12 kg (22.72 tonnes fresh biomass) seed rate of TS-38per ha with 46.63 % and 38.33% reduction of disease incidence over control, respectively. Seed rate of 10 kg per ha resulted in 21.87 tonnes fresh biomass was found to be the least effective, exhibiting the lowest reduction (30.04%) of DI over control (Fig. 1).

Enumeration of Total Microbial Population of Soil

Data presented in Table 2 revealed that the incorporation of brassicaceous crops as biofumigants significantly influenced the total microbial population of soil. In all the treatments, the total microbial population decreased as compared to the initial population. The lowest total microbial population (10.33×10^{-6} CFU g^{-1}) was recorded in T_5 with a seed rate of 18 kg/ha (25.69 tonnes fresh biomass) followed by T_4 with a microbial population of 10.66×10^{-6} CFU g^{1} whereas, the T_1 with a seed rate of 10 kg/ha (21.87 tonnes fresh biomass) exhibited the highest total microbial population (13.00×10^{-6} CFU g^{-1} soil). In terms of reduction of total microbial population over the initial population, the T_5 recorded the highest reduction (51.57 %), followed by T_4 with a reduction of 48.40 % over the initial microbial population (Fig. 2).

Table 1 : Effect of seed rate of biofumigant crop (Rapeseed var.TS-38) on wilt of tomato under *in vivo* conditions

Treatments	14 DAT		21 DAT	
	Disease Incidence (DI) (%)	Reduction of DI over control	Disease Incidence (DI) (%)	Reduction of DI over control
T_1:TS-38@10 kg/ha	48.25^{ab} (43.99)	11.85	54.74^{b} (47.72)	30.04
T_2:TS-38 @12kg/ha	41.76^{bc} (40.25)	23.71	48.25^{b} (43.99)	38.33
T_3:TS-38@14 kg/ha	35.27^{c} (36.43)	35.56	41.76^{b} (40.25)	46.63
T_4: TS-38@ 16 kg	0^{d} (0)	100	0^{c} (0)	100
T_5: TS-38@ 18 kg	0^{d} (0)	100	0^{c} (0)	100
T_6: Control	54.74^{a} (47.72)		78.25^{a} (62.19)	
SEd (±)	5.2		11.54	
CD(P=0.05)	8.6		18.75	

*Data within the parentheses are arcsine-transformed data
Data are the mean of five replications

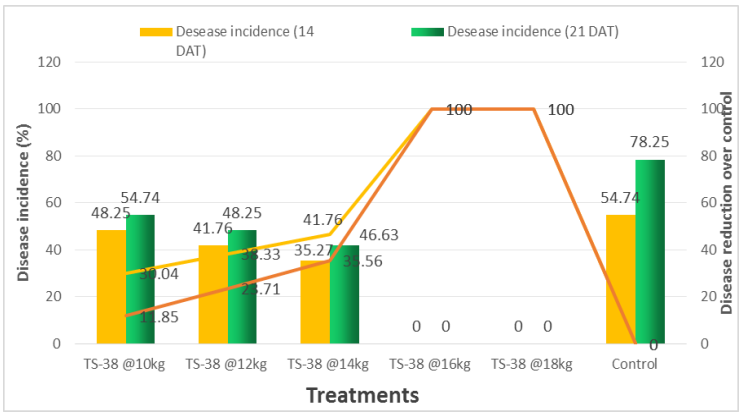

Fig. 1 : Effect of seed rate of biofumigant crop (Rapeseed var. TS-38) on wilt disease of tomato under *in vivo* conditions

Table 2 : Effect of seed rate of biofumigant crop (Rapeseed var. TS-38) on the Total microbial population of soil

Treatment	Total microbial population before treatment ($\times 10^{-6}$ CFU g^{-1} soil)	Total microbial population after treatment ($\times 10^{-6}$ CFU g^{-1} soil)	Reduction of the total microbial population over the initial
T_1:TS-38 @10kg/ha	22.33[a]	13.00[a]	41.78
T_2:TS-38 @12kg/ha	21.66[a]	12.00[ab]	44.59
T_3:TS-38 @14 kg/ha	22.00[a]	11.66[ab]	47.00
T_4:TS-38@ 16 kg/ha	20.66[a]	10.66[ab]	48.40
T_5:TS-38 @ 18 kg/ha	21.33[a]	10.33[b]	51.57
SEd(±)	1.80	1.03	
CD (P=0.05)	4.00	2.30	

Data are the mean of five replications

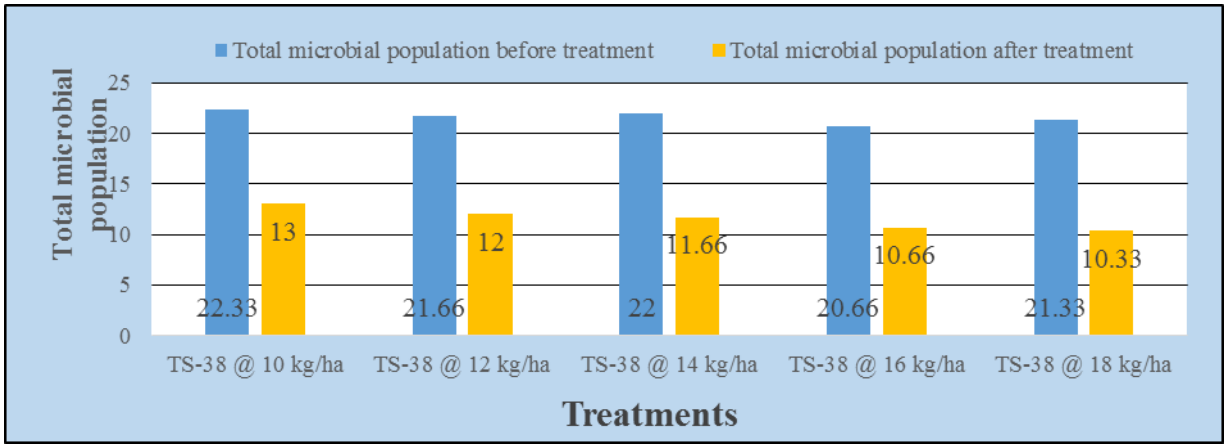

Fig. 2 : Effect of seed rate of biofumigant crop (Rapeseed var. TS-38) on the Total microbial population of soil

Discussion

Symptomology

In the present investigation, the infected plants exhibited light vein clearing of young leaves, yellowing of the lower leaves, which was followed by leaf dropping. The yellowing of leaves was observed in the majority of the plants, browning of vascular tissue causing severe wilting, although leaf yellowing can start on one side of the plant, and later the death of the plant occurs. This could happen on either side of the stalk or both. When the infected stem was sliced open, vascular discolouration or brown streaks were visible. The symptoms observed in the present investigation were also reported by other researchers (Baez-Valdez *et al.*, 2010; Kumar *et al*., 2021; Decal *et al*., 2000).

Patogenicity test

Identification of the Pathogen

In the present investigation, a pathogenicity test was conducted based on Koch's postulates to confirm the pathogen. The roots of the tomato plants showing typical symptoms of the disease were isolated, and tomato seedlings were planted in earthen pots that had

been artificially inoculated with the pure culture of the pathogen by following the procedure described by Muthusamy, (1972). A similar pathogenicity test was also carried out by Jasnic *et al.* (2005). Pathogenicity tests were also performed by other researchers (Abdulkadir *et al.*, 2023; Kumar *et al*., 2013).

Effect of Seed Rate of Biofumigant Crop (Rapeseed var.TS-38) on Wilt of Tomato under *in vivo* conditions.

Seed rates resulting in fresh biomass were found to be significant in reducing the disease incidence of fungal wilt of tomato. The lowest disease incidence (0%) was observed in T_4 and T_5 with a seed rate of 16 kg per ha (24.69 tonnes fresh biomass) and 18 kg per ha (25.69 tonnes fresh biomass), respectively. The highest disease incidence (54.74 %) was observed in T_1 with a seed rate of 10 kg per ha (21.87 tonnes). In regard to the reduction of disease incidence over control, the pot incorporated with fresh biomass of TS-38 @ 24.69 tonnes and 25.69 tonnes resulted highest reduction (100%) of disease incidence over control, followed by fresh biomass of TS-38 @ 23.68 tonnes and 22.72 tonnes with 46.63 % and 38.33% reduction of disease incidence over control, respectively. Incorporation of fresh biomass of TS-38 @ 21.87 tonnes was found to be the least effective, exhibiting the lowest reduction (30.04%) of disease incidence over the control.

F. oxysporum f. sp. *Lycopersici* isolates suppressed by biofumigation with Brassicaspecies containing glucosinolates that release high levels of propenyl isothiocyanate (Smolinska *et al*. 2007; Schroeder and Mac Guidwin, 2010). Abdallah *et al.* (2020) reported that Fresh plant at the flowering stage of the brassica crop *(Brassica juncea)* was found with an inhibition rate of 61.5%, fresh plants at the vegetative stage with 50.2%, and dry plants at both flowering and vegetative stages, with 44.3 % and 39.1 % inhibition rates, respectively, against the pathogen. Parallel results of the effectiveness of isothiocyanate under field conditions, *B. juncea* L. tissues showed the least amount of fungal wilt was reported by Prasad and Kumar (2017). Bharat and Sharma. (2015) reported effective disease control with taramira crop residues for 30 days, and application of formulation of *T. viride* along with FYM and inoculation of transplants with indigenous AM fungi resulted in more than 80% control of *Fusarium* wilt of tomato under polyhouse conditions. Fayzalla *et al.* (2009) conducted a field experiment to evaluate the efficacy of mustard seed meal against the *Fusarium oxysporum*f. sp. *lycopersici.* The fungicidal effect of mustard seed meal against the tested fungi was demonstrated in pot experiments, where disease was suppressed over the control by 69.70%. Relevante and Cumagun. (2012) also assessed the effectiveness of bottlegourd (*Lagenaria siceraria* (Mol.) Stand.) and bittergourd (*Momordica charantia* L.) against *Fusarium* wilt disease by using mustard as a biofumigant. When *F. oxysporum* f. sp. *Momordicae* and *F. oxysporum* f. sp. *lagenariae* isolates were exposed to 5, 10, and 15 g of mustard slurry *in vitro*, their mycelial growth was 100% suppressed as compared to the control.

Enumeration of the total Microbial Population of Soil

Incorporation of brassicaceous crops as biofumigants significantly influenced the total microbial population of soil. In all the treatments, the total microbial population decreased as compared to the initial population. The lowest total microbial population (10.33×10^{-6} CFU g^{-1}) was recorded in T_5 with a seed rate of 18 kg per ha (25.69 tonnes fresh biomass) followed by T_4 with a microbial population of 10.66×10^{-6} CFU g^{-1} whereas, the T_1 with a seed rate of 10 kg per ha (21.87 tonnes fresh biomass) exhibited the highest total microbial population (13.00×10^{-6} CFU g^{-1} soil).In terms of reduction of total microbial population over the initial population, T_5 recorded the highest reduction (51.57 %), followed by T_4 with a reduction of 48.40 % over the initial.

The reduction in pathogen populations resulting from green-manure crops was likely achievable since chlamydospores were sensitive to isothiocyanate. *Pathogenic F. oxysporum* f.sp. *lycopersici* isolates infesting nursery soils would likely be most suppressed by species of plants such as *Brassica carinata, B. nigra, and B. juncea*, which contain glucosinolates that release high concentrations of propenyl isothiocyanate (Smolinska *et al*.,2007). The present observations conformed to the findings of Rao and Viswanath. (2023) on the populations of *Fusarium oxysporum* was significantly reduced by the incorporation of Brassica tissues in soil. Among the six Brassica species tested, incorporation with Mustard tissue recorded the lowest population (3.77×10^{-6}). Where the next was observed with Broccoli tissue (6.56×10^{-6}), followed by Cabbage tissue (7.73×10^{-6}), Cauliflower tissue (10.33×10^{-6}), and Knol khol tissue (12.66×10^{-6}). However, the highest population was observed with treatment with Radish tissue (12.83×10^{-6}). Studies made by Villapudua and Munnecke (1988); Mawar and Lodha (2002); Sintayehu *et al*. (2011); Bharat and Sharma (2015); Gilardi *et al. (*2016); Prasad and Kumar (2017), the biofumigation with seed meal of *B. juncea* induced more than sixty per cent of the fungal population but also showed noticeable enrichment of

bacterial antagonists such as *Bacillus*, *Pseudomonas*, *Streptomyces* spp. They mentioned a dramatic decrease in fungal population after the incorporation of allyl isothiocyanates.

Conclusion

The fungal wilt disease of tomatoes is one of the limiting factors of production. The severity of this disease can be reduced significantly by using brassicaceous plants as a biofumigant. Among all the common brassicaceous crops evaluated, *Brassica napus var.* TS-38 at a seed rate of 18 kg per ha, resulting fresh biomass of 25.69 tonnes per ha, can effectively be used as a biofumigant crop for eco-friendly and sustainable management of fungal wilt disease of tomatoes.

References

Abdallah, I.; Yehia, R. and Kandil, M. A. (2020). Biofumigation potential of Indian mustard (*Brassica juncea)* to manage *Rhizoctonia solani. Egyt. J. Bio. pest control.,* **30(**99), 1-8.

Abdulkadir, H. K.; Ekefan, E. J. and Gwa, V. I. (2023). Pathogenicity of *Fusarium oxysporum* f.sp. *lycopersici* (Sacc.) Isolates in Causing Tomato Wilt Disease on Two Tomato (*Solanum lycopersicum* L.) Varieties. *Bio-Sci. Research Bulletin,* **39**(2), 60-68.

Anonymous. (2018). Horticultural Statistics at a glance, Ministry of Agriculture and Farmers Welfare, Govt. of India. https://agricoop.nic.in/en/statistics/ horticulture. Retrieved on 13/07/22.

Anonymous. (2022a). Statista. https://www.statista.com/statistics/1039712/india-production-volume-of-tomatoes/. Retrieved on 13/06/23.

Anonymous. (2022b). APEDA, National Horticulture Board. https:// agri exchange. apeda. gov.in/India%20 Production/ India Productions. aspx? cat=Vegetables &hs code=1088. Retrieved on 20/06/23.

Baez-Valdez, E.; Carrillo-Fasio, J.; Baez-Sanudo, M.; García-Estrada, R. and Valdez-Torres, J. (2010). Resistant rootstocks utilization for Fusarium control *(Fusarium oxysporum* f. sp. *Lycopersici* (Snyder & Hansen race 3) in tomato (*Lycopersicon esculentum* Mill.) under shade conditions. *Rev. Mex. Fitopatol***., 28**(2), 111-123.

Balanchard, D. (1992). A color atlas of tomato diseases. Wolfe pub. Ltd., Brook house, London, 298.

Balesh, T.; Zapata, F. and Aune, J. B. (2005). Evaluation of mustard meal as organic fertilizer on Tef (*Eragrostis tef* (Zucc) Ttrotter) under field and greenhouse conditions. *Nutr.CyclingAgroecosyst.*,**73**, 49 –57.

Barnett, H. L. and Hunter, B. B. (1972). Illustrated Genera of Imperfect Fungi. Burgess Publication Ltd. St. Paul, Minnnesota, USA, pp. 241.

Bharat, N. K.; and Sharma, J. (2015). Management of Fusarium wilt of tomato under protected conditions using Brassica crop residues, AM fungi, and biocontrol agents. *Indian Phytopathol.*, **68** (3), 287-292.

Decal, A.; Garcia-Lape, R. and Melgarej, P. (2000). Induced resistance by *Penicillianoxalicu*m against *Fusarium oxysporum* f.sp. *lycopersici*: Histological studies of infected and induced tomato stems. *Phytopathol*.,: 260-268.

Devi, N.; Venkataramana, M.; Srivastava, R.K.; Uppalapati, S.R.; Gupta, V.K. and Yli-Mattila, T. (2016). Molecular phylogeny, pathogenicity and toxigenicity of *Fusarium oxysporum* f.sp. *lycopersici*. *Sci. Rep.,* **6**: 21367.

Dutta, P. and Deb, L. (2020). An Innovative technique for artificial inoculation of *Rhizoctonia solani* Kuhn for field experiments. *Int. J. Curr. Microbiol. Appl. Sci.,* **9**(12): 1077-1085.

Fayzalla, E.A.; Barougy, E.E. and Rayes, M.M.E. (2009). Control of Soil-borne pathogenic fungi of soybean by Biofumigation with mustard seed meal. *J. Appl. Sci*., **9**: 2272-2279.

Fleming, A. (2013). Umami: Why the fifth taste is so important. *Guardian*, 9.

Gilardi, G.; Pugliese, M.; Gullino, M. L. and Garibaldi, A. (2016). Effect of different organic amendments on lettuce Fusarium wilt and on selected Soil-borne microorganisms. *Plant Pathol***., 65** (5): 704-712

Gomez, K.A. and Gomez, A.A. (1984). A statistical procedure for agricultural Research. Jon Wiley Sons, New York

Jasnic, S.; Vidic, M.; Bagi, F. and Dordevi, C. V. (2005). Pathogenicity of *Fusarium* species in soybean, **109**: 113-115.

Johnston, A. and Booth, C. (1983). Plant Pathologists Pocket Book. Common Wealth Mycological Institute, Kew, Surrey, England. p. 439.

Karavina, C. and Mandumbu, R. (2012). Biofumigation for crop protection: potential for adoption in Zimbabwe. *J. A. P. Sci.,* 14 (**3):** 1996 –2005.

Kumar, D.; Ratan V.; Kumar, A.; Kumar, S. J.; Pal, K. and Kumar, M. (2013). Pathogenicity tests and antagonistic effect of bioagents on *Fusarium oxysporum* f. sp. *lycopersici* (*FOL*). *Pharma. Inno. J.*,**10** (11): 1887-1891.

Mayee, C.D. and Datar, V.V. (1986). Phytopathometry. Technical Bulletin, Marathwada Agricultural University, *Parbhani*, 125.

Mawar, R.S. and Lodha, S.K. (2002). Brassica amendments and summer irrigation for control of *Macrophomina phaseolina* and *Fusarium oxysporum* f.sp. *Cumini* in hot arid regions. *Phytopathol. Mediterr.*, **41**: 45-54.

Muthusamy, M. (1972). Studies on damping-off of tomato incited by *P. aphanidermatum* (Edson.) Fitz., M.Sc., (Ag.), Thesis. Tamil Nadu Agriculture University, Coimbatore, Tamil Nadu, p. 110.

Parmar, U.; Tembhre, D.; Das, M. P. and Pradhan, J. (2019). Effect of integrated nutrient management on growth, development, and yield traits of tomato (*Solanum lycopersicon* L.). *Int. J. Pharmacogn.*,**8** (3): 2764-2768.

Prasad, P. and Kumar, J. (2017). Management of Fusarium wilt of chickpea using brassicas as biofumigants. *Legume Research***, 40**(1): 178-182.

Prasad, P.; Kumar, J. and Pandey, S. (2015). Biofumigation: Success and prospects in soilborne plant disease management. *Int. J. Appl. Pure Sci. Agric***., 1(**6): 47-59.

Rao, V. G. and Viswanath, H. S. (2023). Biocidal efficacy of plant volatiles obtained from Brassica species against Fusarium wilt of eggplant caused by *Fusarium oxysporum* f. sp. *melongenes. Biol. forum- Int. J.*, **15** (4)**:** 775-782.

Relevante, C. A. and Cumagun, C. J. R. (2013). Control of Fusarium wilt in bittergourd and bottlegourd by

biofumigation using mustard variety. Monteverde. *Arch. Phytopathol. Plant Prot.*, **46** (6): 747-753.

Ricker, A. J. and Ricker, R. S. (1936). Introduction of research on Plant Diseases, John Swift Co., New York, p. 177.

Rudolph, R. E.; Sams, C. and Steiner, R. (2015). Biofumigation performance of four brassica crops in a Green Chile pepper (*Capsicum annuum*) rotation system in Southern New Mexico, *Hort. Sci.*, **50** (2): 247 – 253.

Schroeder, N. E. and Mac Guidwin, A. E. (2010). Mortality and behevior in *Heterodera glycines* juveniles following exposure to isothiocyanates compounds. *J. Nematol.*, **42**(3): 194

Sheoran, O. P. (2006). Online statistical tool (OPSTAT). www.hau.emet.in/about/opstat.php. CCS HAU, Hissar.

Sintayehu, A.; Sakhuja, P.K.; Finisa, C. and Ahmed, S. (2011). Management of Fusarium basal rot (*Fusarium oxysporum* f.sp. c*epae*) on shallot through fungicidal bulb treatment. *Crop Prot.*, **30**(5): 560-565.

Smolinska, U.; Morra, M. J.; Knudsen, G. R. and James, R. L. (2007). Isothiocyanates produced by Brassicaceae species as inhibitors of *Fusarium oxysporum. Plant Dis.*, **87** (4): 407-412.

Tamura, K.; Stecher, G.; Peterson, D.; Filipski, A. and Kumar, S. (2013). MEGA6: molecular evolution genetics analysis version 6.0. *Mol. Biol. Evol.*,**30:** 2725-2729.

Villapudua, R. J. and Munnecke, D. E. (1988). Effect of solar heating and soil amendments of cruciferous residues on *Fusarium oxysporum* f.sp. *conglutinans* and other organisms. *Phytopathol.*, **78:** 289-295.

Wollum, A. G. (1982). Cultural methods for soil microorganisms. *Chemical and microbial properties*, pp.781-814.