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Defeating *Fusarium* wilt disease in sunnhemp fibre crop: A holistic and effective integrated approach

KV Shivakumar and SK Sarkar

Abstract
Sunhemp, a leguminous crop widely grown in tropical regions, is threatened by Fusarium wilt, a soil-borne disease causing significant economic losses. *In vitro* bio-efficacy of five *Trichoderma* isolates and six fungicides were evaluated against the test pathogen. The *Trichoderma* isolate T-1 demonstrated the highest reduction in colony growth (75.13%) and carbendazim, propiconazole, carboxin, and tebuconazole were the most effective fungicides. In a two-year field study, seed treatment with carboxin + thiram, neem cake soil application, and *Trichoderma* sp. combined with intercropping with fodder sorghum showed the lowest mean wilt incidence of 11.35% and highest mean fiber yield of 8.56 q/ha. A comprehensive strategy integrating bioagents, organic amendments, and fungicides can effectively manage *Fusarium* wilt in sunhemp.

Keywords: Sunnhemp, wilt, integrated control, *F. udum* f. sp. *crotolariae*

Introduction

Sunhemp (*Crotalaria juncea*), is a tropical multi-purpose leguminous crop has been used for centuries as a source of fibre, food and medicine. Sunnhemp is grown in almost all states of India either as a fibre crop, green manure or fodder crop. The cultivation of sunnhemp in India spans across 9.3 thousand hectares of land, which yields a production of 7.56 thousand tons of fiber. This crop is primarily cultivated for fiber production in the states of Odisha, Madhya Pradesh, Uttar Pradesh, Maharashtra, Chhattisgarh, Bihar, Rajasthan, and West Bengal (MOA & FW, 2020) [12]. The main economic product derived from sunnhemp is the fiber extracted from its bark, which is known for its high cellulose content, low lignin content, and minimal ash content (Vanishree *et al.*, 2019) [28]. These properties of sunnhemp fiber make it an ideal raw material for the manufacture of various products such as tissue paper, cigarette paper, currency paper, ropes, twines, fishing nets, canvas etc (Sanjoy Shil *et al.*, 2018) [24]. It is also immensely popular as green manure and cover crop in various regions worldwide due to its remarkable benefits. Its cultivation significantly enhances the physical, chemical, and biological properties of the soil in a natural manner. The crop's extensive production of organic matter effectively enriches the soil. Furthermore, the nitrogen fixed by the symbiotic process provides a substantial proportion of the succeeding crop's nitrogen requirements (Divya Bhayal *et al.*, Ozores-Hampton, 2012) [4, 14].

Overall, sunnhemp is an important crop that offers many benefits to farmers and the environment. One of the major obstackle of sunnhemp cultivation is the incidence of diseases especially in monsoon-sown crop. Several diseases affect the crop among which vascular wilt, sunnhemp mosaic and anthracnose are the major ones which leads to economic losses. In some cases, the vascular wilt incidence rate can reach as high as 60-80% under favorable conditions, and a study conducted by (Uppal and Kulkarni in 1937) [27] found that greenhouse circumstances can lead to wilt incidence rate of up to 88% in which seedling conditions were severely impacted, with losses exceeding 60%. However, the incidence rate was even higher in seed crops due to the favorable conditions that provide a breeding ground for the diseases. Further studies conducted by Wang and Dai (2018) [30] revealed 13% of the plants displayed symptoms of the disease in six farms from Tainan, southern Taiwan. The infected plants gradually wither, droop, and hang down, eventually turning brown and dying within one or two days. In adult plants, the wilting parts droop at the tips, leading to defoliation and ultimately, death. Therefore, this study aims to examine the prevalence of wilt disease in the major sunhemp growing areas of Uttar Pradesh. Additionally, it aims to develop integrated management strategies that incorporate both organic and inorganic amendments to effectively manage the disease.

Materials and Methods

Sampling, isolation and morphological identification of pathogen and native antagonists

The survey was carried out between June to July 2019 in the key sunnhemp (*Crotalaria juncea*) growing regions of Uttar Pradesh, namely Amethi, Pratapgarh, and Prayagraj districts. During the survey, plant samples displaying typical wilt symptoms, including general yellowing of the lower leaves and discoloration of vascular bundles, were collected. The fungus was isolated by following the standard tissue isolation method using infected plant parts. Subsequently, a pure culture of the fungus was obtained through hyphal tip culture under aseptic conditions. To facilitate further studies, the obtained culture was maintained on PDA slants at a temperature of 4 ^{0}C. To prove its pathogenicity, soil inoculation was performed. The fungus was identified as *Fusarium udum* f sp. *crotolariae* based on its distinct morphological features (Leslie and Summerell, 2006; Wang and Dai, 2018) [10, 30].

For isolation of native antagonists, soil samples were collected from rhizosphere of healthy sunnhemp plants in Easter Uttar Pradesh, India. The collected samples were transported to the laboratory and stored at 4°C until used. To isolate *Trichoderma* spp., serial dilutions (up to five-fold) were prepared for each soil sample using sterilized distilled water. A 0.5 mL of diluted sample was then spread on the surface of Trichoderma Specific Medium (TSM) and incubated at 28±2°C for 96 hours. Morphologically distinct colonies observed on the plates were purified using Potato Dextrose Agar (PDA) (Krishna Kumar *et al.,* 2012)[8]. Based on cultural and morphological traits isolates were identified and confirmed as *Trichoderma* sp (Sammuls, 1996; Kumar *et al.,* 2020.) [23, 9].

Bio-efficacy of fungicides and antagonists against test pathogen in laboratory condition

To assess the efficacy of fungicide molecules against *F. udum* f. sp. *crotolariae*, an *in vitro* experiment was conducted using the Poison food technique. Six fungicide molecules were tested at three different concentrations (0.25%, 0.05%, and 0.1%) by preparing a fungicidal suspension in PDA, where the required quantity of fungicide was added to obtain the desired concentration based on the active ingredient present in the chemical. Twenty ml of the poisoned medium was then poured into each sterilized Petri plate. A mycelial disc measuring 5 mm in diameter was extracted from a five-day-old culture's periphery and placed in the center, followed by incubation at 25±1 °C until the fungus growth touched the periphery in the control plate. Suitable checks were also maintained without the addition of any fungicide, and four replications were conducted for each treatment. The colony's diameter was measured in two directions, and an average was calculated to determine the percentage of inhibition of mycelial growth (Vincent, 1927) [29].

To evaluate the potential antagonistic effect of five native *Trichoderma* isolates, a dual culture technique was employed. A disk measuring 5 mm in diameter was extracted from both the *Trichoderma* and test pathogen, and subsequently positioned 6 cm apart from each other on the edges of the Petri dish. To serve as a control, Petri dishes were inoculated on one edge with test fungus. The Petri dishes were incubated at 28°C until the test fungus fully covered the control plates. To determine the percentage of inhibition (PI), the formula developed by Otadoh *et al.* (2011) [13] was utilized: PI (%) = (R1-R2/R1) × 100, where R1 refers to the mycelial growth of the fungus in the control dishes, and R2 represents the mycelial growth of the fungus in the presence of the antagonist. Each treatment was replicated four times, and the experiment was conducted twice.

Integrated disease management under field conditions

To address the issue of sunnhemp wilt, field experiments were conducted at Sunnhemp Research Station, Pratapgarh, Uttar Pradesh, India. Two highly effective fungicides and one best *Trichoderma* isolate (T-1), along with neem cake and an organic indigenous liquid formulation (Jeevamrutha), as determined by *in vitro* studies, were tested in combination and evaluated for their efficacy in maize (cv. African tall) and sorghum (cv. M. P. Chari) intercropping system over two years (2020 and 2021). The experiment included nine treatments with three replications. The liquid organic formulation (Jeevamrutha) was prepared by combining 10 kg of locally-sourced cow dung with 10 litres of cow urine, 2 kg of organic jaggery, 2 kg of pulse flour, and a handful of soil from the same field. These ingredients mixed thoroughly in a large tank, then placed the tank in a shaded area covered it with a breathable jute bag and incubated for five days. During this time, it was stirred vigorously three times a day in clock wise direction with a wooden stick for 10-15 minutes each time (Palekar, 2006) [16]. Observations on plant height, basal diameter and wilt incidence were recorded on 60 and 90days after sowing. Wilt incidence was calculated with the help of the following formulae:

Wilt incidence (WI)% = Number of plants infected by wilt disease/Total number of plants observed X 100. Fibre yield of net plot was noted down after retting process and calculated in q ha-1.

Treatments details

T_1 = Soil application of organic liquid formulation (Jeevamrutha) @ 500 lit/ha + seed treatment *Trichoderma* sp (T-1) @ 5 g/kg seed + intercropping with maize (10:1)

T_2 = Soil application of organic liquid formulation (Jeevamrutha) @ 500 lit/ha + *Trichoderma* sp (T-1) @ 5 g/kg seed + intercropping with sorghum (10:1)

T_3 = Seed treatment with carboxin + thiram @ 2 g/kg seed + soil application of neem cake @ 250 kg/ha and *Trichoderma* sp. (T-1) @ 2.5 kg/ha + intercropping with maize (10:1)

T_4 = Seed treatment with carboxin + thiram @ 2g/kg seed + soil application of neem cake @ 250 kg/ha and *Trichoderma* sp. (T-1) @ 2.5 kg/ha + intercropping with sorghum (10:1)

T_5 = Seed treatment with tebuconazole @1ml/kg seed + soil application of neem cake @ 250 kg/ha and *Trichoderma* sp. (T-1) @ 2.5 kg/ha + intercropping with maize (10:1)

T_6 = Seed treatment with tebuconazole @1ml/kg seed + soil application of neem cake @ 250 kg/ha and *Trichoderma* sp. (T-1) @ 2.5 kg/ha + intercropping with sorghum (10:1)

T_7 = Seed treatment with carbendazim @ 2g/ Kg seed + soil application of neem cake @ 250 kg/ha and *Trichoderma* sp. (T-1) @ 2.5 kg/ha (Positive check)

T_8 = Seed treatment with *Trichoderma* sp (T-1) @ 5g/ kg seed + soil application of neem cake @ 250 Kg/ha and *Trichoderma* sp. @ 2.5 kg/ha + intercropping with sorghum (10:1) + soil application of organic liquid formulation

(Jeevamrutha) @ 500 lit/ ha @ 40 DAS
T_9 = Control (Negative check)

Statistical Analysis

The experiment was carried out in a completely randomized design (CRD) for *in vitro* experiments and randomized complete block design (RCBD) for field experiments using WASP-Web Agri Stat Package 2.0 (ICAR Research Complex for Goa, India). The critical difference (CD, $p \leq 0.05$) was used to compare treatment means using Dun-can's multiple range test.

Results and Discussion

Sampling, isolation and identification of pathogen and *Trichoderma* sp

A survey was carried out between June and July, 2019 in major sunnhemp cultivation regions of Uttar Pradesh, namely Amethi, Pratapgarh, and Prayagraj districts. Plants exhibiting characteristic wilting symptoms were gathered to isolate pathogen, along with rhizosphere soil samples collected from healthy plants to recover antagonists. The first sign of sunnhemp wilt is the yellowing of leaves and a loss of turgidity, which causes the leaves to droop and hang down. Eventually, the affected leaves turn brown and dry up, followed by the drying of the entire plant (as shown in Fig. 1). Although complete plant wilting is common, partial wilting can also occur. In mature plants, the upper portion droops and defoliation gradually occurs, ultimately leading to plant death. At that stage, when the stem of the infected plant split open laterally near the soil level, a brownish vascular discoloration became visible. Symptoms observed in infected plants were consistent with those described in previous studies (Choi *et al.*, 2018; Wang and Dai, 2018) [2, 30].

The pathogen was successfully isolated on PDA medium. The fungus isolated during the study exhibited greyish mycelium with flattened growth. Its macroconidia were falcate and had three to four septa with hooked apical cells, while its microconidia were oval to reniform with 0 to 1 septa. The fungus also produced chlamydospores either singly, in pairs, or in short chains. Based on these morphological characteristics, it was determined that the isolate is closely related to *F. udum*. (Fig. 2). Further pathogenicity test was performed on sunnhemp seedlings confirmed that *F. udum* sp. *crotolariae* causing wilt disease in sunnhemp. The morphological characteristics of the isolated fungus, including its macroscopic and microscopic features, were consistent with those reported for *F. udum*. a known pathogen causing wilt in pigeon pea, but its pathogenicity was only confirmed on sunnhemp seedlings. Therefore, to differentiate it from other isolates of *Fusarium udum* that infect other host plants, it was named as *Fusarium udum* f. sp. *crotalariae* (Padwick, 1937; Zhang *et al.*, 1986; Wang and Dai, 2018) [15, 30, 32].

In vitro screening of native *Trichoderma* strains as potential biocontrol agents against *Fusarium udum* f. sp. *crotalariae*

Totally six isolates of *Trichoderma* sp recovered from rhizosphere of sunnhemp (Table 1). All isolates were screened to evaluate the ability of the isolates to act as antagonists against *F. udum* f. sp. *crotalariae*, by dual culture technique. All tested *Trichoderma* isolates were observed to reduce the growth of *F. udum* f. sp. *crotalariae*, with isolate T-1 exhibiting the highest inhibition percentage of 75.13% followed by production of cell wall-degrading enzymes, and the secretion of antimicrobial compounds (Harman *et al.*, 2004) [6].

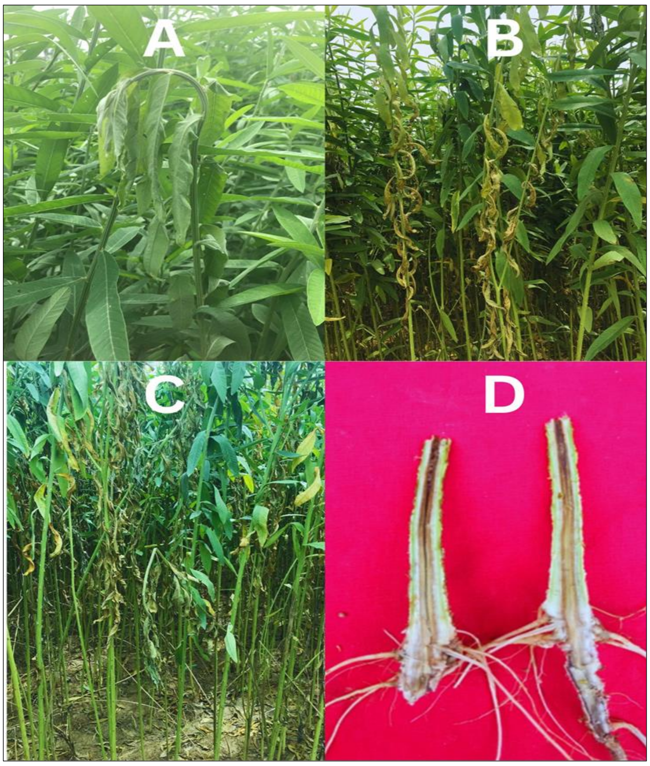

Fig 1: Sunnhemp plant showing typical wilt symptoms: A) Drooping of young leaves; B) Progress of yellowing flowed drying of leaves; C) Complete wilted plants & D) Brown vascular discoloration

T-2 with 66.50%. The least inhibition was observed in T-3, which showed a 52.75% reduction in mycelial growth. These results clearly indicate that the *Trichoderma* isolates have potential as biocontrol agents against *F. udum* f. sp. *Crotalariae* (Table 2 & Fig. 3). Similarly, a study by Kapoor Shash *et al.* (2018) [7] found that local isolate of *Trichoderma viride* exhibited strong antagonistic activity against *Fusarium oxysporum* f. sp. *udum*. The observed growth inhibition by *Trichoderma* isolates against *F. udum* f. sp. *crotalariae* may be due to several mechanisms such as competition for nutrients,

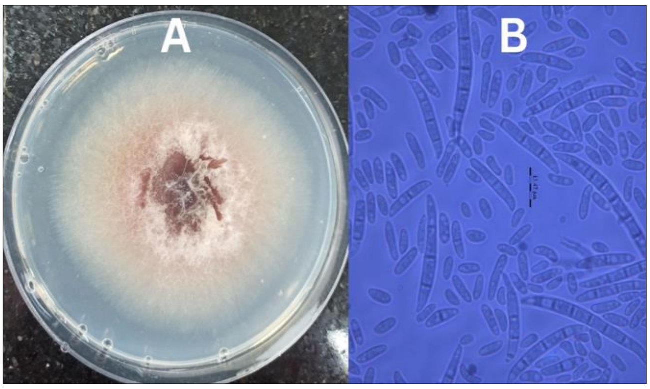

Fig 2: Cultural and morphological characteristics of *F. udum* f.sp. *crotolariae* (A) pinkish to grey mycelium; (B) micro and hooked macroconidia

Table 1: Fungal native antagonists isolated from rhizosphere of sunnhemp

Sl. No	Isolates designation	Place of collection	Colony colour	Fungal native antagonists
1	T_1	Sunnhemp Research Station, Pratapgarh, U.P.	Green	*Trichoderma* sp.
2	T_2	Sur mauo, Pratapgarh, U.P.	Green	*Trichoderma* sp.
3	T_3	Tikar mafi, Ameti, U.P.	Dark green	*Trichoderma* sp.
4	T_4	Shivagad, Prayagraj, U.P.	Light green	*Trichoderma* sp.
5	T_5	Kalyanpur, Pratapgarh, U.P.	Dark green	*Trichoderma* sp.

Table 2: *In vitro* efficacy of bio agents against *F. udum f. sp. Crotolariae*

Sl. No.	Bioagents	Per cent inhibition
1	*Trichoderma sp.* (T-1)	75.13 (60.07)*a
2	*Trichoderma sp.* (T-2)	66.50 (54.62)b
3	*Trichoderma sp.* (T-3)	52.75 (46.57)d
4	*Trichoderma sp.* (T-4)	57.63 (49.38)c
5	*Trichoderma sp.* (T-5)	56.46 (48.70)c
CD @ 0.01 & 0.05		4.658 & 3.275
CV		2.918
p value		<0.0001

*Figures in parentheses indicate angular transformed values; values followed by the same letters are not significantly different at p = 0.05, Duncan's multiple range test.

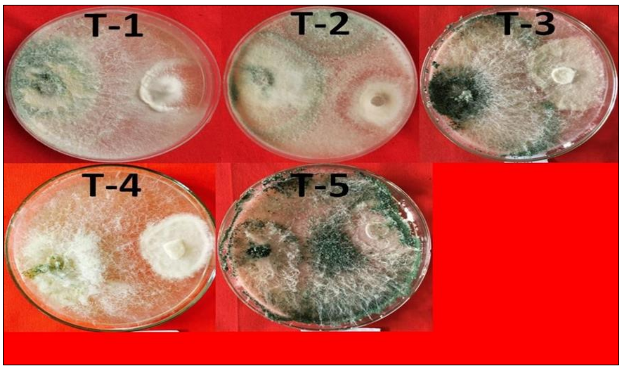

Fig 3: Inhibition zones created by different *Trichoderma* isolates against *F. udum* f.sp. *crotolariae*

In vitro screening of fungicides against *Fusarium udum* f. sp. *Crotolariae*

The results showed that all six fungicides were effective in inhibiting the growth of *F. udum* f.sp. *crotalariae*. However, there were significant differences in their efficacy. Carbendazim 50% WP, propiconazole 13.9% + difenoconazole 13.9% EC, carboxin 37.5% + thiram 37.5% WS, and tebuconazole 25.9% EC were highly effective, completely inhibiting (100%) the growth of *F. udum* f.sp. *crotalariae*. Propineb 54.2% + tricyclazole 15% WP and hexaconazole 5% SC showed the least inhibition of mycelial growth, with only 67.38% and 76.90% inhibition, respectively, even at the highest concentration (0.1%) compared to the other tested fungicides (Table 3 & Fig. 4**).** Several previous workers reported similar efficacy of carboxin + thiram (Pradhya Khilare *et al.*, 2020; Rajvanshi *et al.*, 2018) [19, 20], carbendazim (Mehta *et al.*, 2010; Reddy and Kumar, 2021) [11, 12], propiconazole (Ghante *et al.*, 2019) [5] and tebuconazole (Chennakesavulu *et al.*, 2013) [3] in laboratory conditions.

Azole fungicides are a class of compounds have been widely used in the management of *Fusarium* wilt disease. Studies have investigated the mechanisms by which azole fungicides exert their antifungal activity against *Fusarium* species. One of the main targets of azole fungicides is the enzyme sterol 14α-demethylase (CYP51), which is involved in the biosynthesis of ergosterol, a critical component of fungal cell membranes (Yang *et al.*, 2022) [31]. The first generation systemic fungicide (e.g., carboxin) was developed in the 1960s and used as a seed treatment against many soil borne fungi. Carboxin inhibits the mitochondrial complex II enzyme, succinate dehydrogenase leading to a decrease in energy production and a disruption of cellular metabolism (Ulrich and Mathre, 1972) [26], while on the other hand, thiram, an organic sulfur fungicide, is known for its broad-spectrum disease control and multi-site mode of action. As a result, it is frequently used in combination with single-site fungicides in resistance management strategies. This combination approach helps to increase the efficacy of disease control while reducing the risk of fungicide resistance.

Table 3: *In vitro* efficacy of fungicides against *F. udum f. sp. Crotolariae*

Sl. No.	Fungicides		Per cent inhibition		
			Concentration (%)		
	Common name	Trade name	0.025	0.05	0.1
1	Carbendazim 50% WP	Bavistin	100a (89. 96)*	100a (89.96)	100a (89.96)
2	Propiconazole 13.9% + Difenoconazole 13.9% EC	Taspa	100a (89. 96)*	100a (89.96)	100a (89.96)
3	Propineb 54.2% + Tricyclazole 15% WP	Lancia	41.19b (39.92)	48.69b (44.24)	67.38c (55.16)
4	Carboxin 37.5% + Thiram 37.5% WS	Vitavax power	100a (89.96)	100a (89.96)	100a (89.96)
5	Hexaconazole 5% SC	Contaf	24.52c (29.67)	33.37c (35.28)	76.90b (61.26)
6	Tebuconazole 25.9% EC	Folicur	100a (89.96)	100a (89.96)	100a (89.96)
Mean			77.61 (61.75)	80.33 (63.66)	90.71 (72.24)
CD @ 0.01 &0.05			5.815 & 4.148	5.889 & 4.2	6.304 & 4.496
CV			3.003	2.938	2.786
P value			<0.0001	<0.0001	<0.0001

*Figures in parentheses indicate angular transformed values; values followed by the same letters are not significantly different at p = 0.05, Duncan's multiple range test.

Integrated disease management under field conditions

The treatments performed best under lab studies were further evaluated under field conditions in different combinations, along with neem cake and an organic indigenous liquid formulation (Jeevamrutha) in in maize (*cv.* African tall) and sorghum (*cv.* M.P. Chari) intercropping system over two years (2020 and 2021) at Sunnhemp Research Station, Pratapgarh, U.P., India. Result revealed that minimum wilt incidence (11.35%) was recorded from the treatment where seed treated with carboxin + thiram @ 2 g/kg seed + soil application of neem cake @ 250 kg/ha and *Trichoderma* sp. (T-1) @ 2.5 kg/ha + intercropping with sorghum (10:1) followed by seed treated with carboxin + thiram @ 2g/kg seed + soil application of neem cake @ 250 kg/ha and *Trichoderma* sp. (T-1) @ 2.5 kg/ha + intercropping with maize (10:1) (12.03%) with reduction of wilt disease incidence over control 74.61 and 73.09 per cent respectively compared to control 44. 71 per cent (Table 4) with maximum fibre yield (8.56), (8.53) q/ha respectively compared to untreated control which recorded highest wilt incidence of 44.71 per cent and lowest fibre yield of 4.34 q/ha (Table 5). The incidence of wilt disease showed no significant variation in the combined data of two years for these two treatments. However, seed treatment with *Trichoderma* sp (T-1) @ 5 g/ kg seed + soil application of neem cake @ 250 Kg/ha and *Trichoderma* sp. @ 2.5 kg/ha + intercropping with sorghum (10:1) + soil application of organic liquid formulation (Jeevamrutha) @ 500 lit/ ha @ 40 DAS was the third best treatment showed encouraging results in suppressing wilt incidence but could not overcome the fungicide combined superior treatments.

The efficacy of these treatments could be attributed to the combined effect of carboxin and thiram in seed treatment, which provided protection against seed-borne fungal pathogens, and the soil application of neem cake, which acted as a biocontrol agent against soil-borne pathogens. In addition, the intercropping with fodder sorghum or maize provided a physical barrier against the spread of wilt disease. Pradeep Kumar (2015) [18] reported the effectiveness of seed treatment with *T. viride* in combination of carboxin in reducing white rot of pea. The potentiality of *Trichoderma* sp present in combination with other chemical and natural amendments in integrated management schedule was already established in reducing *Fusarium oxysporum* f. sp. *udum* (Pawar *et al.*, 2013; Singh and Singh, 2020) [17, 25]. Intercropping systems have been shown to suppress disease development by altering the soil environment, thereby making it less conducive for pathogen development. The decrease in wilt incidence in sunnhemp intercropped with sorghum has been attributed to the secretion of fungitoxic exudates by sorghum roots. Rangaswami and Balasubramanian (1963) [21] reported that sorghum roots secrete hydrocyanic acid, which can delay the germination of spores of *Fusarium moniliforme* (Sheld.). They also observed that during the early stages of plant growth, this fungus was unable to establish itself in the rhizosphere of sorghum genotypes. Similarly, Chang *et al.* (2022) [1] reported that by altering the rhizosphere bacterial community and driving more beneficial microorganisms to accumulate in the soybean rhizosphere, maize-soybean relay strip intercropping could help the host resist soil-borne *Fusarium* root rot. Overall, the findings suggest that the use of a combination of fungicides and biological control agents, along with organic amendments and inclusion of sorghum or maize as rotation or intercrop could be an effective strategy to manage the disease.

Table 4: Effect of different treatments on *Fusarium* wilt incidence in sunhemp

Sl. No.	Treatments	Wilt incidence (%) 2020	Wilt incidence (%) 2021	Pooled data	Disease control over control (%)
T_1	S.A. of OLF @ 500 lit/ha + *Trichoderma* sp S.T. @ 5g/ kg seed + IC with maize (10:1)	11.87def	24.33bc	18.08cd	59.56
T_2	S.A. of OLF @ 500 lit/ha + *Trichoderma* sp. S.T. @5g/ kg seed + IC with sorghum (10:1)	14.80de	24.00bc	19.40c	56.60
T_3	S.T. with carboxin + thiram @ 2g/kg seed + S.A. of neem cake @250 kg/ha and *Trichoderma* sp. (T-1) @2.5 kg/ha + intercropping with maize (10:1)	9.03f	15.03d	12.03e	73.09
T_4	S.T. with carboxin + thiram @ 2g/kg seed + S.A. of neem cake @250 kg/ha and *Trichoderma* sp. (T-1) @2.5 kg/ha + intercropping with sorghum (10:1)	12.79def	9.90e	11.35e	74.61
T_5	S.T. with tebuconazole @1ml/kg seed + S.A. of neem cake @ 250 kg/ha and *Trichoderma* sp. @ 2.5 kg/ha + IC with maize (10:1)	19.50bc	22.67bc	21.09bc	52.82
T_6	S.T. with tebuconazole @1ml/ kg seed + S.A. of neem cake @ 250 Kg/ha and *Trichoderma* sp. @ 2.5 kg/ha + IC with Sorghum (10:1)	21.17d	27.33b	24.25b	45.76
T_7	S.T. with Carbendazim @ 2g/ kg seed + S.A. of neem cake @ 250 kg/ha and *Trichoderma* sp. @ 2.5 kg/ha (Positive check)	15.53cd	21.03c	18.28cd	59.11
T_8	S.T. with *Trichoderma* sp @ 5g/ kg seed + S.A. of Neem cake @ 250 kg/ha and *Trichoderma* sp. @ 2.5 kg/ha + IC with Sorghum (10:1) + S.A. of OLF @ 500 lit/ ha @ 40 DAS	10.63ef	20.26c	15.44d	65.46
T_9	Control (Negative check)	43.33a	46.08a	44.71a	-
	CD @ 0.01 & 0.05	5.823 & 4.226	6.559 & 4.76	4.383 & 3.18	-
	CV	13.849	11.751	8.955	-
	p value	<0.0001	<0.0001	<0.0001	-

* Mean of three replications; values followed by the same letters are not significantly different at $p = 0.05$, Duncan's multiple range test.

Table 5: Effect of different treatments on plant height, basal diameter and fibre yield of sunhemp in the year 2020 and 2021

Sl. No.	Treatments	Fibre yield (q/ha)		Pooled data	Per cent yield increase over control (%)
		2020	2021		
T1	S.A. of OLF @ 500 lit/ha + *Trichoderma* sp S.T. @ 5g/ kg seed + IC with maize (10:1)	7.97abc	6.98bc	7.48bc	73.96
T2	S.A. of OLF @ 500 lit/ha + *Trichoderma* sp. S.T. @5g/ kg seed + IC with sorghum (10:1)	6.92cd	7.37bc	7.15c	64.75
T3	S.T. with carboxin + thiram @ 2g/kg seed + S.A. of neem cake @250 kg/ha and *Trichoderma* sp. (T-1) @2.5 kg/ha + intercropping with maize (10:1)	8.97a	8.09b	8.53a	96.54
T4	S.T. with carboxin + thiram @ 2g/kg seed + S.A. of neem cake @250 kg/ha and *Trichoderma* sp. (T-1) @2.5 kg/ha + intercropping with sorghum (10:1)	7.13bc	9.98a	8.56a	97.23
T5	S.T. with tebuconazole @1ml/kg seed + S.A. of neem cake @ 250 kg/ha and *Trichoderma* sp. @ 2.5 kg/ha + IC with maize (10:1)	5.87de	7.23bc	6.55d	50.92
T6	S.T. with tebuconazole @1ml/ kg seed + S.A. of neem cake @ 250 Kg/ha and *Trichoderma* sp. @ 2.5 kg/ha + IC with Sorghum (10:1)	5.27ef	6.48bc	5.88e	35.48
T7	S.T. with Carbendazim @ 2g/ kg seed + S.A. of neem cake @ 250 kg/ha and *Trichoderma* sp. @ 2.5 kg/ha (Positive check)	6.88cd	6.96bc	6.92cd	59.44
T8	S.T. with *Trichoderma* sp @ 5g/ kg seed + S.A. of Neem cake @ 250 kg/ha and *Trichoderma* sp. @ 2.5 kg/ha + IC with Sorghum (10:1) + S.A. of OLF @ 500 lit/ ha @ 40 DAS	8.20ab	7.33bc	7.76b	78.81
T9	Control (Negative check)	4.40f	4.27d	4.34f	-
	CD @ 0.01 & 0.05	1.572 & 1.141	1.598 & 1.16	0.777 & 0.564	-
	CV	9.629	9.32	4.64	-
	p value	<0.0001	<0.0001	<0.0001	-

* Mean of three replications; values followed by the same letters are not significantly different at $p = 0.05$, Duncan's multiple range test

Conclusion

The findings of this study suggest that a combination of different treatments can effectively manage wilt disease in sunnhemp fibre crops intercropped with maize or sorghum. The use of carboxin + thiram seed treatment, neem cake soil application, and *Trichoderma* sp. (T-1) along with intercropping with either maize or sorghum resulted in a significant reduction in wilt disease incidence, along with an improvement in plant growth and fibre yield. Although the addition of an organic liquid formulation (Jeevamrutha) showed some positive results, it was not as effective as the combined fungicide treatments. These results highlight the potential of integrated management strategies for wilt disease in sunnhemp fibre cultivation, which could have practical applications in the agricultural sector.

Conflict of interest: None.

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