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CONTENTS

Effective management strategies against ginger rhizome rot caused by *Fusarium solani* by the application of chemicals, bioagents and Herbal *Kunapajala* in mid hills of Uttarakhand

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ABSTRACT: Ginger (*Zingiber officinale* Rosc.) is a high value cash crop which is grown in different states of India including Uttarakhand, a hilly area situated in northern Himalayas. The low productivity of ginger is due to prone to various diseases and insect pests in which rhizome rot disease is one of the major obstacles caused by the fungus *Pythium* spp. and *Fusarium* spp. that reduces the yield potential drastically and may cause economic damage of 50-90 % to the crop under conducive environmental conditions. Rhizome rot disease is one of the most important ginger diseases in view of severe crop losses as it directly affects the economic part of the plant. Keeping this in view, a field experiment was conducted to evaluate the efficacy of different chemical and non-chemical treatments against ginger rhizome rot. The experiment was comprised of 14 treatments (T_1 to T_{14}) including Control (untreated), applied as seed treatment followed by two soil drenching. All the treatments were found significantly superior towards plant growth promotion, rhizome yield and disease suppression when compared to untreated control. However, the treatment T_6 (Metalaxyl 3.3% + Chlorothalonil 33.1% SC) was found best with respect to disease suppression (81.09% ROC) and yield (14.01 t/ha) followed by T_5 (Metalaxyl 4%+ Mancozeb 64% WP) with 78.66 % ROC for rhizome rot and yield of 13.89 t/ha and T_{13} (*Trichoderma harzianum* @ 0.5% +*Pseudomonas fluorescence* @ 0.5%) with 78.60% ROC for rhizome rot and yield of 13.42 t/ha which were statistically at par. With respect to plant growth promotion, treatment T_{13} (*Trichoderma harzianum* @ 0.5% +Pseudomonas fluorescence @ 0.5%) was found best with maximum number of tillers, plant height and number of leaves followed by T_{14} (Herbal *Kunapajala* @ 12.5%), T_{11} (*Trichoderma harzianum* @ 1%) and T_{12} (*Pseudomonas fluorescence* @ 1%). The highest cost benefit ratio (1: 2.56) was recorded with the treatment T_{13} whereas the next highest ratios of 1: 2.53 and 1: 2.50 were achieved with the treatments T_6 and T_5, respectively. This study, thus, concludes that all the treatments reduced severity of disease and improved plant growth traits though the treatment T_{13} was found most promising and economic when applied as seed treatment along with two periodic soil drenching as it minimized ginger rhizome rot and at the same time improved growth parameters and yield with highest cost benefit ratio followed by the treatments T_6 and T_5 under present experimental materials and conditions.

Key words: Ginger, herbal *Kunapajala*, *Pseudomonas fluorescence,* rhizome rot, *Trichoderma harzianum*

Ginger is a perennial cash crop that belongs to the family Zingiberaceae with 47 genera and 1,400 species (Hogarth, 2000**).** Ginger is native to South East Asia and it is grown in most of the tropical and subtropical regions of the world. It thrives well up to an altitude of 1500 meters above mean sea level in the Himalayas, the optimum being 300 to 900 m. According to FAO (2019), the total cultivated area of ginger in India is 164 thousand ha while the production and productivity is 1788 thousand tonnes and 109.02 tonnes ha^{-1}, respectively. Ginger rhizome is widely used throughout the world for both medicinal and culinary purposes because of its ethnic medicinal and nutritional value. Recent estimation by health scientists have shown that ginger has a role in reducing certain disease such as diabetes, high blood pressure and also have anticancer and anti-inflammatory properties **(**Hamilton, 2011; Krell and Stebbing, 2012; Zivarpour *et al.,* 2021).

Uttarakhand occupies 1.81 million ha and 19.07 MT production with a very low productivity as reported by NHB in 2018. The continuous uses of degenerated seeds which are prone to various biotic and abiotic factors cause low productivity which seems to be barrier in foreign exchange also. Although major foliar diseases do exist, rhizome rot disease is one of the most important in view of severe crop losses as it directly affects the economic part of the plant. Generally, farmers can identify the disease by above

ground symptoms *viz*., yellowing and wilting of whole plant (Gogoi *et al.,* 2008; Behera *et al.,* 2020). As symptoms on older leaves progress, younger leaves start developing a similar symptom progression until the entire plant dies **(**Indo Swiss Project Sikkim, 2005**).** At the ground level, there are white- brown lesions that occur in the rhizome-stem intersection or "collar" region. These lesions gradually enlarge and coalesce which results in rot and collapse in stem (Dohroo, 2005). The wet soil condition, high soil moisture and soil temperature are important predisposing factors that aggravates disease development (Dake, 1995; Meenu and Jebasingh, 2019).

Looking to the severity of disease and economic loss, there is a critical need to investigate and develop rapid and effective management strategies against ginger rhizome rot. Management of ginger rhizome rot is challenging because *Pythium* spp. and *Fusarium* spp. can survive in soil for many years once introduced and single approach does not work efficiently to suppress the pathogens under field conditions (Meenu and Kaushal, 2017). One of the most common means of controlling plant diseases in the field, in the greenhouse, and, sometimes, in storage is through the use of chemical compounds that are toxic to the pathogens. Although, each fungicide has different target sites and mode of actions, the majority of fungicides work by targeting certain cell organelles and interfering with their cellular processes to prevent harmful fungi from growing. Unlike chemical fungicides, use of bio-control agents is considered as an effective and eco-friendly approach in management of plant pathogenic fungi. Various bio-control agents such as bacteria, fungi, and actinomycetes have already been proven to be effective in inhibiting the growth of a variety of pathogens including *Pythium* and *Fusarium* species and improving growth parameters in various crops (Rai *et al.,* 2018; Rawat *et al*., 2013; Rawat *et al.,* 2012). *Kunapajala* is a liquid organic manure that reaches to root zone in a short time. Secondly, the ingredients of *Kunapajala* have been fermented, which means the mass (proteins, fats, etc.) is already broken down into simple low molecular weight products, and therefore nutrients from which would become available to plants faster than conventionally applied organic matter (Neff *et al.*, 2003). Application of Herbal *Kunapajala* has been found helpful in plant growth promotion and enhancing the immunity of plant **(**Kavya and Ushakumari, 2020). Therefore, the present study was undertaken to investigate for exploring the effective and economically feasible disease management strategies against rhizome rot of ginger.

MATERIALS AND METHODS

Experimental site

The present experiment was conducted at Vegetable Research Block and Laboratory of Plant Pathology Division, College of Forestry, Ranichauri, Tehri Garhwal, Uttarakhand during the crop season March-November of 2020. Geographically, the location is located at 30^0 18' N latitude and 78° 24' E longitude, at an elevation of 1700 to 2200 meters above mean sea level.

The experimental plot and plant geometry

The experiment was laid out in Randomized Block Design consisting of fourteen treatments with three replications and each treatment was assigned randomly in plots of the experimental field during the experimentation. The plots of 1.8 m × 1.8 m with a spacing of 40 cm from row to row and 20 cm from plant to plant were maintained.

Preparation of *Trichoderma* formulation

The biocontrol agent *Trichoderma harzianum* was taken from the repository of Biocontrol Laboratory of Plant Pathology Division, College of Forestry, Ranichauri. Mass culture of *Trichoderma* was prepared on barnyard millet (*Echinochloa frumentaceae*) grains (locally known as "Jhangora/ Sawan") as described by Rawat *et al.* (2013). To obtain the optimal concentration of biocontrol agents in the talc formulation, spore powder was mixed with 350 mesh talcum powder (95 per cent whiteness) and 1 per cent carboxy methyl cellulose (CMC), which was used as a sticker. The final *Trichoderma* inoculum was adjusted to 5 X 10^6 CFU/g in the

prepared formulation.

Preparation of *Pseudomonas* formulation

Mass production of *Pseudomonas fluorescens* was done using raw talc powder. King's broth was prepared and filled in 150 ml conical flasks and autoclaved. The biocontrol agent *Pseudomonas fluorescens* was taken from the repository of Biocontrol Laboratory of Plant Pathology Division, College of Forestry, Ranichauri The flasks were then inoculated with the tested isolate of fluorescent *Pseudomonas* and incubated at 28± 2 °C for 48-72 h in an incubator shaker at 150 rpm. Broth with optimum colony forming by *Pseudomonas fluorescens* was mixed thoroughly with pre-sterilized raw talc (1:2 v/w) having 1.0 % carboxymethyl cellulose (CMC). The formulation was dried and final inoculum load was maintained approximately 10^7 CFU /g.

Preparation of Herbal *Kunapajala*

For the preparation of Herbal *Kunapajala*, fresh and green leaves (10 kg) of *Eupatorium odoratum* (Kala Bansa), *Azadirachta indica* (Neem), *Rubus ellipticus* (Hisalu), and *Berberis aristata* (Barberry) were used. The leaves were chopped into small pieces shearing the veins and kept in a cylindrical container, after that cow dung (10 kg), cow urine (10 lit), jaggery (1kg), sprouted black gram (1kg), butter milk (1 lit) and water (40 lit) were mixed in 3- 4 layers. Then the lid of the container was closed for fermentation. The mixture was stirred thoroughly with a bamboo pole twice a day, in both clockwise and anticlockwise directions, for 20 days. After 20 days, it was filtered and used (Kavya and Ushakumari, 2020).

Treatment details and their application

All the treatments were applied as seed treatment and two periodic soil drenching. For the seed treatment, healthy rhizomes were selected out and dipped into the solution of different treatments for 30 minutes. After that, rhizomes were dried in the shade for 2-3 hours before sowing. First soil drenching was done at 120 days after sowing, and second was done at 150 days after sowing. The details of different treatments used in the present study are as T_1= Control, T_2 = Carbendazim 50% WP @ 0.2%, T_3 = Mancozeb 75% WG @ 0.3 %, T_4= Carbendazim 12% + Mancozeb 63% WP @ 0.3 %, T_5 = Metalaxyl 4% + Mancozeb 64% WP @ 0.25%, T_6= Metalaxyl 3.3% + Chlorothalonil 33.1% SC @ 0.25%, T_7= Copper oxychloride 50% WG @ 0.25%, T_8 = Propiconazole 25% EC @ 0.1 %, T_9= Hexaconazole 5% SC @ 0.1%, T_{10}= Tebuconazole 25.9 % EC @ 0.1%, T_{11}= *Trichoderma harzianum* @ 1%, T_{12}= *Pseudomonas fluorescence* @ 1%, T_{13} = *Trichoderma harzianum* + *Pseudomonas fluorescence* @ 0.5 % each and T_{14}= Herbal *Kunapajala* @ 12.5 %.

Isolation of pathogen from infected rhizomes

Diseased samples were collected from the Control (untreated) plot and washed thoroughly in tap water. Diseased samples along with healthy tissues were cut into small pieces and superficially sterilized using 0.1 % $HgCl_2$. The cut pieces were then placed aseptically on to sterilized potato dextrose agar medium fortified with 30µg/ml streptomycin in petri plates and incubated at 25± ^{0}C.

Pathogenicity test

Fresh and healthy rhizomes were selected from the untreated (Control) plot. Healthy rhizomes almost of equal size, washed in sterile distilled water and surface sterilized by using 1% sodium hypochlorite for 5 min followed by repeated washing with sterile distilled water. A sterilized cork borer of 0.25 cm diameter was used to make a small cavity about 0.25 cm deep in the centre of the rhizome. In each cavity, a small amount of inoculum from the periphery of a 7 days old culture was placed and the bit of the tissue was replaced and sealed with wax. The rhizomes without inoculum served as Control. The treated rhizomes were incubated at 25± ^{0}C for 15 days, with periodic checkup for rotting or pathogen growth on the rhizome. Pathogen was then again re-isolated from infected rhizome and compared with the original one (Agrawal *et al.*, 2008; Mekurai and Alemu, 2020).

Observations and analysis

Data on germination (%), plant height (cm), number of tillers per plant, number of leaves per plant, disease incidence, disease severity (0-5 scale) and

yield were recorded. Germination per cent was recorded at 60 days after sowing. Plant height, number of tillers per plant and number of leaves per plant were recorded from 5 randomly selected plants from each plot when plants attained maximum height at 160 days after sowing.

Disease incidence was recorded from 120 days after sowing and continued up to maturity at 30 days interval. Disease severity was recorded using a 0-5 scale on harvested rhizomes where, 0 = No infection on rhizome; 1 = 0.1 -5.0 % rotting of rhizome; 2 = 5.1 -15.0 % rotting of rhizome; 3 = 15.1 -30.0 % rotting of rhizome; 4 = 30.1 -60.0 % rotting of rhizome; 5 = More than 60 % rotting of rhizome (Figure 1).

The weight of healthy rhizomes per plot, diseased rhizomes per plot and total yield per plot was recorded at harvest and total yield was then converted into per hectare yield.

The isolated pathogen was identified on the basis of growth and characteristic features of the mycelium as well as spore morphology observed under the compound microscope. Confirmation of the genus was done by noting down the type and arrangement of spores on mycelium, by referring standard literatures (Barnet and Hunter, 1972).

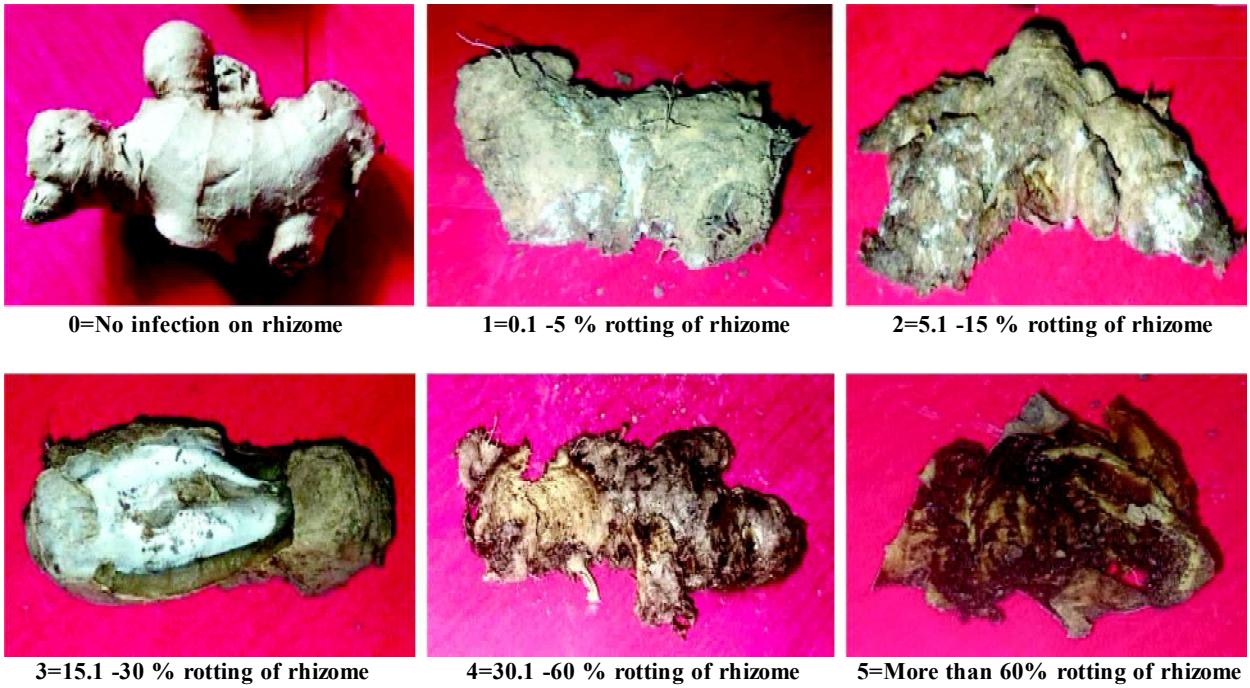
The treated rhizomes incubated at 25± ^{0}C temperature for 15 days were checked periodically for rotting or pathogen growth on the rhizome. Pathogen was then again re-isolated from infected rhizome and compared with original one (Agrawal *et al*., 2008; Mekurai and Alemu, 2020).

The data were analyzed statistically through OPSTAT programme, described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Plant growth parameters

The maximum germination Per centage (96.30 %) was recorded in treatment T_6 (Metalaxyl + Chlorothalonil) followed by the treatments T_5 (Metalxyl + Manocozeb) with 93.33 %, and T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) with 91.11 % whereas, minimum



0=No infection on rhizome **1=0.1 -5 % rotting of rhizome** **2=5.1 -15 % rotting of rhizome**

3=15.1 -30 % rotting of rhizome **4=30.1 -60 % rotting of rhizome** **5=More than 60% rotting of rhizome**

Fig. 1: Disease scale (0-5) used in the present study for scoring disease severity for rhizome rot in harvested rhizome

germination Per centage (80.74 %) was observed in T_1 (Control). The results are closely matched with the findings of Singh (2011) and Ayub *et al.* (2009) who reported that application of Metalaxyl + Mancozeb resulted maximum in seed germination followed by *Trichoderma harzianum* application.

The maximum plant height (84.23 cm) was recorded in plants treated with T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) followed by T_{14} (Herbal *Kunapajala*) with 82.01 cm in each, T_{11} (*Trichoderma harzianum*) with 80.60 cm and T_{12} (*Pseudomonas fluorescens)* with 78.67 cm plant height.

Significantly maximum number of tillers per plant (8.00) was recorded with the treatment T_{13} (*Trichoderma harzianum + Pseudomonas fluorescens*) followed by T_{14} (Herbal *Kunapajala*) with 7.56 number of tillers whereas minimum number of tillers per plant (4.67) was recorded in treatment T_1 (Control) followed by T_7 (Copper oxychloride) with 5.44 tillers per plant

All the treatments showed significant effect on the number of leaves per plant, the maximum number of leaves per plant (62.22) was recorded with treatment T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) followed by T_{14} (*Herbal Kunapajala*) with 56.33 number of leaves per plant whereas, the minimum number of leaves per plant (29.33) was found in T_1 (Control), followed by T_7 (Copper oxychloride) and T_3 (Mancozeb) with 36.21 and 39.06 leaves per plant, respectively.

These plant growth related research outcomes are in promise with the findings of Ram *et al.* (1999) where they reported combination of *Trichoderma harzianum* and *Pseudomonas* spp. best in plant growth promotion including germination. *T. viride* /

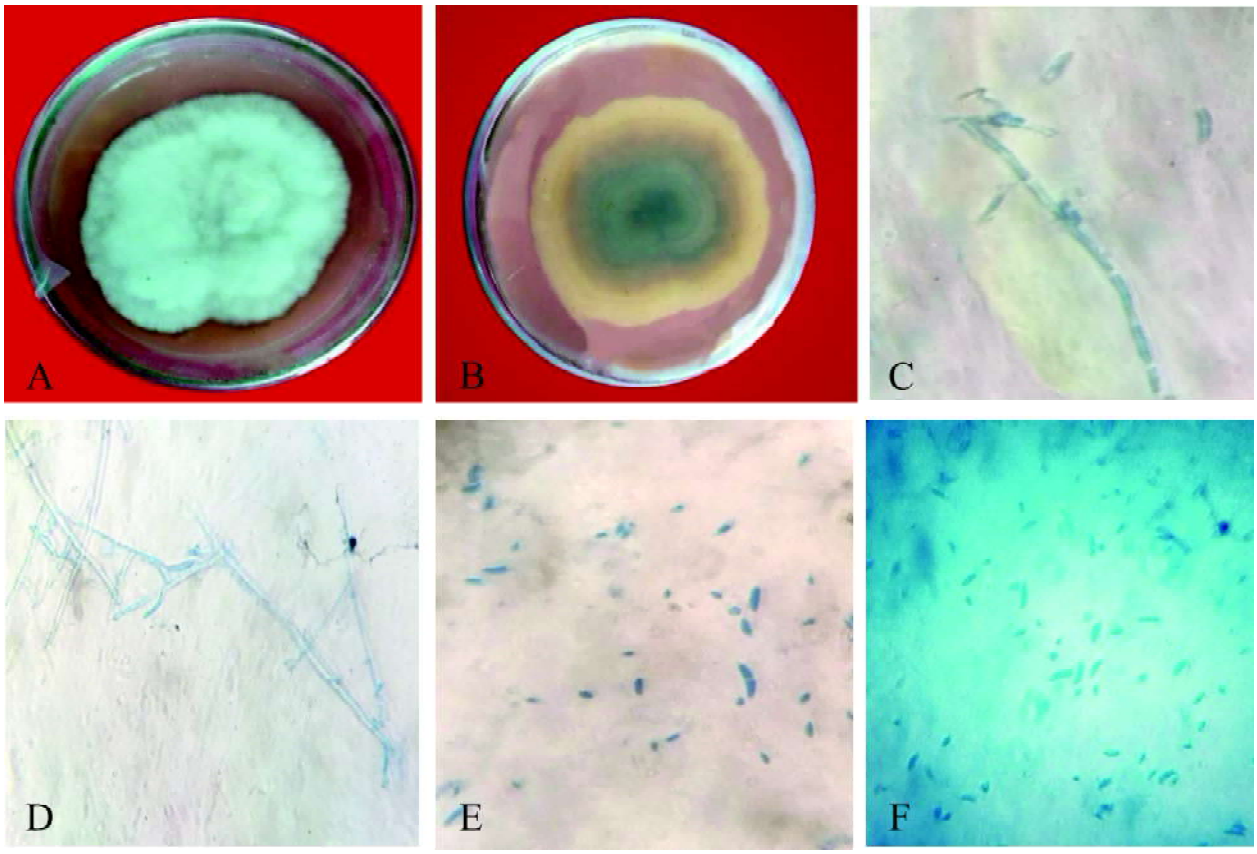


Fig. 2: A. Front view of colony growth of *Fusarium solani*, B. Reverse view of colony growth of *Fusarium solani*, C. Septate mycelium D. Branched mycelium, E. Macro and micro conidia

T. harzianum and *P. fluorescens* were reported to be compatible and improved plant growth of chilli and tomato significantly when these were applied together (Rini and Sulochana, 2006; Chaube and Sharma, 2002). The present findings also corroborate with Pandey (2019) who previously reported that Herbal *Kunapajala* improves the crop growth. Anoop and Bhai (2014) and Dohroo *et al.* (2015) have also exhibited better efficacy in plant growth by the use of *Trichoderma harzianum*. Ushamalini

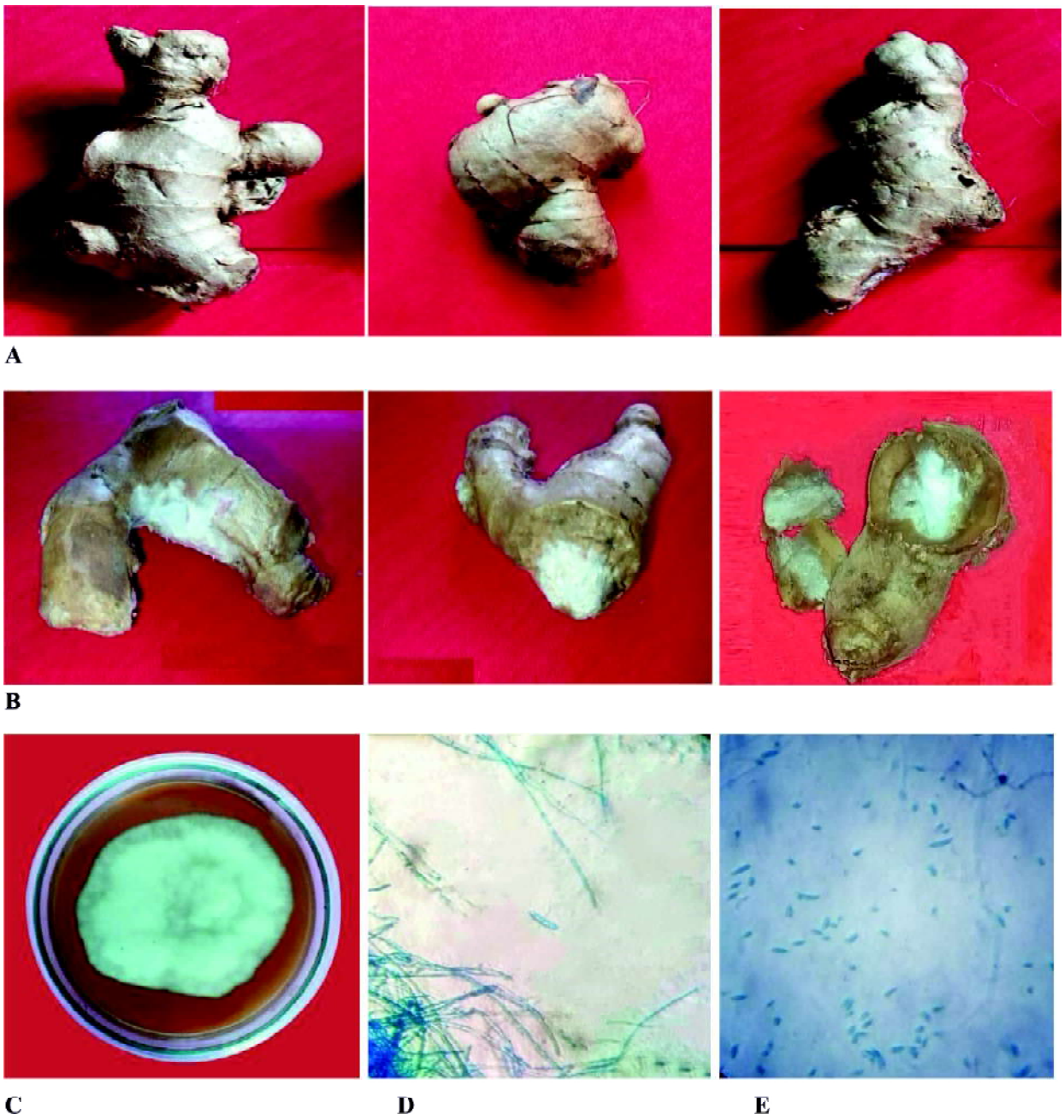


Fig. 3: A. Experimental rhizomes without the inoculation of pathogen (Control), B. Experimental rhizomes inoculated with the culture of pathogen, C. Colony growth/characteristics of the re-isolated pathogen from the inoculated experimental rhizome, D. Septate and branched mycelium observed under the microscope, E. Macroconidia and microconidia observed under the microscope

Table 1: Effect of different treatments on germination (%), plant height (cm), number of tillers per plant and number of leaves per plant of ginger crop under field conditions

Symbol	Treatment	Concentration	Germination (%)	Plant height (cm)	Tiller number	Leaf number
T_1	Control	-	80.74	64.02	4.67	29.33
T_2	Carbendazim (50% WP)	0.2%	87.41	73.69	5.89	44.56
T_3	Mancozeb (75% WP)	0.3%	83.70	71.89	5.55	39.06
T_4	Carbendazim + Mancozeb (12%+63% WP)	0.3%	84.44	73.52	5.66	42.00
T_5	Metalaxyl + Mancozeb (4%+64% WP)	0.25%	93.33	77.00	6.56	46.33
T_6	Metalaxyl + Chlorothalonil (3.3%+33.1% SC)	0.25%	96.30	77.67	6.67	47.33
T_7	Copper oxychloride (50% WP)	0.25%	82.22	70.79	5.44	36.21
T_8	Propiconazole (25% EC)	0.1%	88.15	74.39	6.11	45.56
T_9	Hexaconazole (5% SC)	0.1%	90.37	76.47	6.33	46.11
T_{10}	Tebuconazole (25.9% EC)	0.1%	88.89	74.91	6.22	45.67
T_{11}	*Trichoderma harzianum* (10g/lit)	1%	85.19	80.60	7.33	48.78
T_{12}	*Pseudomonas fluorescens* (10g/lit)	1%	85.93	78.67	7.00	47.42
T_{13}	*Trichoderma harzianum* + *Pseudomonas fluorescens* (5g +5g/lit)	0.5%+ 0.5%	91.11	84.23	8.00	62.22
T_{14}	Herbal *Kunapajala* (125ml/lit)	12.5%	82.96	82.01	7.56	56.18
	C D	-	3.792	3.129	0.286	1.886
	SEM	-	1.297	1.070	0.098	0.645
	SE(d)	-	1.835	1.514	0.138	0.912
	C V	-	2.577	2.449	2.666	2.457

Table 2: Effect of different treatments on PDI in ginger crop at 120, 150, 180 and 210 days after sowing (DAS) under field conditions

Symbol	Treatment	Concentration	Disease Incidence (%)				
			120 DAS (%)	150 DAS (%)	180 DAS (%)	210 DAS (%)	ROC (%)
T_1	Control	-	8.23	18.73	43.21	60.13	0.00
T_2	Carbendazim (50% WP)	0.2%	2.96	8.96	12.99	18.75	68.82
T_3	Mancozeb (75% WP)	0.3%	5.78	11.09	15.91	23.99	60.10
T_4	Carbendazim + Mancozeb (12%+63% WP)	0.3%	5.19	10.37	15.62	25.99	56.78
T_5	Metalaxyl + Mancozeb (4%+64% WP)	0.25%	0.00	2.01	8.93	12.83	78.66
T_6	Metalaxyl + Chlorothalonil (3.3%+33.1% SC)	0.25%	0.00	0.42	8.66	11.37	81.09
T_7	Copper oxychloride (50% WP)	0.25%	6.12	12.22	27.29	35.57	40.84
T_8	Propiconazole (25% EC)	0.1%	2.96	8.48	12.23	17.46	70.76
T_9	Hexaconazole (5% SC)	0.1%	1.48	5.59	10.12	15.88	73.59
T_{10}	Tebuconazole (25.9% EC)	0.1%	2.22	7.65	11.59	16.02	73.36
T_{11}	*Trichoderma harzianum* (10g/lit)	1%	0.74	3.76	9.22	13.96	76.78
T_{12}	*Pseudomonas fluorescens* (10g/lit)	1%	0.74	5.31	9.45	15.65	73.97
T_{13}	*Trichoderma harzianum* + *Pseudomonas fluorescens* (5g +5g/lit)	0.5%+ 0.5%	0.00	3.32	9.00	12.87	78.60
T_{14}	Herbal *Kunapajala* (125ml/lit)	12.5%	5.78	11.78	18.33	26.28	56.29
	C D	-	0.18	0.29	0.71	0.84	-
	SEM	-	0.06	0.10	0.24	0.28	-
	SE(d)	-	0.08	0.14	0.34	0.40	-
	C V	-	3.57	2.20	2.27	2.28	-

PDI: Per cent disease incidence; DAS: Days after sowing; ROC: Reduction over control

et al. (2019) have reported better plant growth parameters including germination in ginger crop by the application of *Pseudomonas fluorescens*.

Disease assessment

A remarkable performance of all the treatments was observed in reducing the disease incidence, observed

Table 3: Effect of different treatments on per cent disease severity of harvested ginger rhizomes

Symbol	Treatment	Concentration	Disease severity (%)	Score (G)
T_1	Control	-	53.21	4
T_2	Carbendazim (50% WP)	0.2%	15.55	3
T_3	Mancozeb (75% WP)	0.3%	18.89	3
T_4	Carbendazim + Mancozeb (12%+63% WP)	0.3%	15.94	3
T_5	Metalaxyl + Mancozeb (4%+64% WP)	0.25%	7.78	2
T_6	Metalaxyl + Chlorothalonil (3.3%+33.1% SC)	0.25%	4.73	1
T_7	Copper oxychloride (50% WP)	0.25%	36.23	4
T_8	Propiconazole (25% EC)	0.1%	13.56	2
T_9	Hexaconazole (5% SC)	0.1%	12.78	2
T_{10}	Tebuconazole (25.9% EC)	0.1%	13.00	2
T_{11}	*Trichoderma harzianum* (10g/lit)	1%	10.56	2
T_{12}	*Pseudomonas fluorescens* (10g/lit)	1%	11.67	2
T_{13}	*Trichoderma harzianum* + *Pseudomonas fluorescens* (5g +5g/lit)	0.5%+ 0.5%	9.92	2
T_{14}	Herbal *Kunapajala* (125ml/lit)	12.5%	26.74	3
	C D	-	0.833	
	SEM	-	0.285	
	SE(d)	-	0.403	
	C V	-	2.757	

Table 4: Effect of different treatments on total yield of ginger crop grown under field conditions

Symbol	Treatment	Concentration	Yield (kg/plot)	Infected rhizome (kg/plot)	Healthy rhizome (kg/plot)	Yield (t/ha)	Increase over control (%)
T_1	Control	-	3.10	1.58	1.52	8.61	-
T_2	Carbendazim (50% WP)	0.2%	4.17	0.57	3.60	11.58	34.49
T_3	Mancozeb (75% WP)	0.3%	3.97	0.63	3.34	11.04	28.22
T_4	Carbendazim + Mancozeb (12%+63% WP)	0.3%	4.08	0.58	3.50	11.31	31.36
T_5	Metalaxyl + Mancozeb (4%+64% WP)	0.25%	5.00	0.35	4.65	13.89	61.32
T_6	Metalaxyl + Chlorothalonil (3.3%+33.1% SC)	0.25%	5.05	0.31	4.74	14.01	62.72
T_7	Copper oxychloride (50% WP)	0.25%	3.82	0.71	3.11	10.61	23.23
T_8	Propiconazole (25% EC)	0.1%	4.22	0.50	3.72	11.72	36.12
T_9	Hexaconazole (5% SC)	0.1%	4.53	0.45	4.08	12.58	46.11
T_{10}	Tebuconazole (25.9% EC)	0.1%	4.33	0.47	3.86	12.03	39.72
T_{11}	*Trichoderma harzianum* (10g/lit)	1%	4.70	0.38	4.32	13.06	51.68
T_{12}	*Pseudomonas fluorescens* (10g/lit)	1%	4.67	0.41	4.26	12.97	50.64
T_{13}	*Trichoderma harzianum* + *Pseudomonas fluorescens* (5g +5g/lit)	0.5%+ 0.5%	4.83	0.36	4.47	13.42	55.87
T_{14}	Herbal *Kunapajala* (125ml/lit)	12.5%	3.87	0.66	3.21	10.73	24.62
	C D	-	0.168	0.035	0.139	0.536	-
	SEM	-	0.057	0.012	0.048	0.183	-
	SE(d)	-	0.081	0.017	0.067	0.259	-
	C V	-	2.331	3.626	2.209	2.652	-

at 120, 150, 180 and 210 DAS, when compared to the untreated Control (Table 2). The highest disease incidence was recorded in T_1 (Control) whereas minimum disease incidence was recorded in the treatment T_6 (Metalaxyl + Chlorothalonil) followed by T_5 (Metalaxyl + Mancozeb) and T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) which were statistically at par. The maximum reduction over control (81.09 %) was found with the treatment T_6 (Metalaxyl + Chlorothalonil) followed by the treatments T_5 (Metalaxyl + Mancozeb) with 78.66 % ROC and T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) with 78.60 % ROC which were statistically at par to each other.

The lowest disease severity (4.73 %) with 1G was recorded in T_6 (Metalaxyl + Chlorothalonil) followed by T_5 (Metalaxyl + Mancozeb) with 7.78

Table 5: Estimation of C: B ratio of different treatments on ginger crop grown under field conditions

Symbol	Treatment	Concentration	Gross Return/ha	Cost of Cultivation/ ha (Rs)	Net Return/ ha(Rs)	Cost: Benefit
T_1	Control	-	210472.2	239280	-28807.78	1:0.88
T_2	Carbendazim (50% WP)	0.2%	500220.8	244824	255396.83	1:2.04
T_3	Mancozeb (75% WP)	0.3%	463916.7	244824	219092.67	1:1.89
T_4	Carbendazim + Mancozeb (12%+63% WP)	0.3%	485473.6	253188	232285.61	1:1.92
T_5	Metalaxyl + Mancozeb (4%+64% WP)	0.25%	645915.3	258075	387840.28	1:2.50
T_6	Metalaxyl + Chlorothalonil (3.3%+33.1% SC)	0.25%	657845.8	259860	397985.83	1:2.53
T_7	Copper oxychloride (50% WP)	0.25%	431550	247575	183975.00	1:1.74
T_8	Propiconazole (25% EC)	0.1%	516258.3	246798	269460.33	1:2.09
T_9	Hexaconazole (5% SC)	0.1%	566081.9	245244	320837.94	1:2.31
T_{10}	Tebuconazole (25.9% EC)	0.1%	535804.2	249388	286416.17	1:2.15
T_{11}	*Trichoderma harzianum* (10g/lit)	1%	599637.5	242880	356757.5	1:2.47
T_{12}	*Pseudomonas fluorescens* (10g/lit)	1%	591551.4	242880	348671.4	1:2.44
T_{13}	*Trichoderma harzianum* + *Pseudomonas fluorescens* (5g +5g/lit)	5%+ 0.5%	620720.8	242880	377840.8	1:2.56
T_{14}	Herbal *Kunapajala* (125ml/lit)	12.5%	445288.9	248730	196558.89	1:1.79

% (2G) and T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) with 9.92 % (2G) whereas the highest disease severity was observed with treatment T_1 (Control) with 53.21 % disease severity and score of 4G (Table 3). The present findings are in line with the findings of Hasant *et al.* (2014) and Jain *et al.* (2020) who reported in their investigation that the treatment Metalaxy + Mancozeb effectively suppressed the incidence and severity of rhizome rot disease. Combination of *T. harzianum* and *P. fluorescens* was reported to be best in controlling the disease of wilt caused by *Fusarium oxysporium* (Khan *et al.*, 2004; Rini and Sulochana, 2006). Combination of *T. harzianum* and a bacterial BCA (*Pseudomonas* sp.) has given high efficacy in disease suppression in the study reported by Ram *et al.* (1999). Abdel Wahed (2019) has previously reported that Folio gold (Metalaxyl 3.3% + Chlorothalonil 33.1% SC) significantly decreases the per centage of root rot disease in basil caused by the *Fusarium spp.*

Yield

A significant variation was observed in the rhizome yield due to the application of different treatments which was ranged from 3.10 kg/plot to 5.05 kg/plot as presented in the Table 4. The highest rhizome yield was recorded with the treatment T_6 (Metalaxyl + Chlorothalonil) with 5.05 kg/plot followed by T_5 (Metalaxyl + Mancozeb) with 5.00 kg/plot and T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) with 4.83 kg/plot which were statistically at par to each other whereas lowest yield per plot was recorded in T_1 (Control) and T_7 (Copper oxychloride) with 3.10 kg/plot and 3.82 kg/plot, respectively.

Among all the treatments, the highest weight (1.58 kg/plot) of infected rhizomes was recorded in T_1 (Control) while lowest weight (0.31 kg/plot) of infected rhizomes was measured in T_6 (Metalaxyl + Chlorothalonil) followed by T_5 (Metalaxyl + Mancozeb) with 0.35 kg/plot and T_{12} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) with 0.36 kg/plot which were again found statistically at par with each other.

The maximum weight (4.74 kg/plot) of the healthy rhizomes was recorded in treatment T_6 (Metalaxyl + Chlorothalonil) followed by T_5 (Metalaxyl + Mancozeb) with 4.65 kg/plot and T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) with 4.47 kg/plot. The lowest weight (1.52 kg/plot) of the healthy rhizomes was recorded in T_1 (Control).

The highest yield increase over control (62.72 %) was observed with the treatment T_6 (Metalaxyl + Chlorothalonil) followed by T_5 (Metalaxyl + Mancozeb) with 61.32 % increase over control and T_{13} (*Trichoderma harzianum* + *Pseudomonas fluorescens*) with 55.87 % increase over control,

whereas the lowest per centage of yield increase over control (23.23 %) was observed with the treatment T_7 (Copper oxychloride).This finding supports the previous studies of Ghorpade and Ajri (1982), Ayub *et al*. (2009) and Jain *et al.* (2020) who reported that Metalaxyl + Mancozeb was to be the best in contributing maximum yield in ginger. Ram *et al.* (1999) and Debnath *et al.* (2010) reported that maximum yield was found in the plot when treated with the combination of *Trichoderma* spp. and *Pseudomonas fluorescens.*

Cost: Benefit

All the treatments showed significant effect on cost benefit ratio. Cost benefit ratio calculated from the different treatments excluding Control ranged from 1: 1.74 (T_7) to 1: 2.56 (T_{13}). The highest cost benefit ratio (1: 2.56) was recorded with the treatment T_{13} (*Trichoderma harzianum + Pseudomonas fluorescens*) whereas the next highest ratio of 1: 2.53 and 1: 2.50 were achieved with the treatments T_6 (Metalaxyl + Chlorothalonil) and T_5 (Metalaxyl + Mancozeb), respectively as depicted in Table 5. The lowest cost benefit ratio (1:0.88) was achieved with the treatment T_1 (Control). The results are closely matched with the findings of Jayasekhar *et al*. (2000) who evaluated fungicidal seed ginger treatment as well as BCAs (*Trichoderma harzianum* + neem cake or *Trichoderma viride* + neem cake) and reported that the highest cost benefit ratio was found in *Trichoderma harzianum* + neem cake application followed by 0.1% Metalaxyl.

Identification of the isolated pathogen

On the basis of cultural characteristics, the isolated pathogen showed white cottony with fluffy growth and raised mycelium with smooth margin. The microscopic study of pathogen revealed that the mycelium was branched, septate and hyaline. Macroconidia and microconidia were observed under the microscope. Microconidia were oval to round shaped with 0-1 septate while the macroconidia observed were sickle shaped with 2-3 septa. Clamydospores were intercalary, spherical and hyaline. The isolated pathogen was identified as *Fusarium solani* based on our observed characteristics (Figure 2). Microscopic observations confirmed by referring the standard literature (Barnett and Hunter, 1972; Alexopoulos *et al*., 1996).

Confirmation of isolated pathogen

In pathogenicity test, all the experimental rhizomes inoculated with isolated pure culture of pathogen induced white dense mycelia on the external surface, and the internal part showed brown discoloration with rotting of rhizomes. The pathogen was then reisolated by tissue plating method, from the samples taken from the infected experimental rhizomes and thereafter identified by microscopic observation. The microscopic observation showed septate with branched mycelium, sickle shaped macroconidia and round to oval microconidia. It was thus same as shown in the microscopic observation of pure culture (Figure 3). Above mentioned symptoms were also previously reported by Mekuria *et al.* (2013).

CONCLUSION

From the present study, it can be concluded that the treatments exerted significant effect on disease control and yield though the maximum disease control and highest yield was observed in treatment T_6 (Metalaxyl + Chlorothalonil) followed by T_5 (Metalaxyl + Mancozeb) and T_{13} (*Trichoderma harzianum + Pseudomonas fluorescens*). With respect to plant growth parameters, treatment T_{13} (*Trichoderma harzianum + Pseudomonas fluorescens*) and T_{14} (Herbal *Kunapjala*) have been found best and at the same time showed significant effect on yield and disease control when compared to Control. From the present study, the treatment T_{13} can be assumed as most effective and economical as the maximum cost benefit ratio was recorded from the same. In the present era, humans are becoming more conscious for own health that's why more ecological approaches are now being researched. In recent years, there has been a worldwide swing to the use of eco-friendly methods for protecting the crops from pests and diseases. The challenge today is how to achieve not only food security but also food safety by employing effective measures for biological control of plant pathogens in agriculture. From the present study, it may be concluded that *Trichoderma harzianum* (0.5 %) + *Pseudomonas*

fluorescens (0.5 %) was most promising and economic when applied as seed treatment and two periodic soil drenching as it minimized ginger rhizome rot incited by *Fusarium solani* and improved growth parameters and yield with highest cost benefit ratio followed by Metalaxyl + Chlorothalonil (3.3%+33.1% SC) and Metalaxyl + Mancozeb (4%+64% WP).

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