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Effect of integrated diseases management (IDM) modules for the management of stripe rust of wheat

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Abstract

Wheat (*Triticum aestivum* L.) is highly affected by stripe rust disease in northern India. Several management practices apply in wheat for the management of wheat rust; however, IDM practices are more effective. They reduced application of fungicide on wheat cultivation. Effect of IDM modules showed maximum shoot length as was recorded in S.A. of *Tirchoderma* through FYM, S.T. with *Azotobacter*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing (32.05 cm) and (34.00 cm) and among all the treatments, maximum number of tillers were recorded in S.A. of *Tirchoderma* through FYM, S.T. with *Azotobacter*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing (2.89 and 3.00) during 2018-19 and 2019-20, respectively. Among all these treatments, minimum disease severity was recorded in case of S.A. of *Tirchoderma* through FYM, S.T. with *Azotobacter*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing (5.33%) (9.13%) and (3.75%) at 80, 90, and 100 days after sowing, respectively during 2018-19. Soil application of *Tirchoderma* through FYM, seed treatment with *Azotobacter*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage also more effective against (81.87%) disease severity and was decrease over control. In case of disease incidence, minimum disease incidence against yellow rust of wheat was recorded in S.A. of *Tirchoderma* through FYM, S.T. with *Azotobacter*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing (13.90%), (19.10%) and (21.21%) at 80, 90, and 100 days after sowing, respectively during 2019-20.

1. Introduction

Wheat (*Triticum aestivum* L.) crop is the important crop belonging to the Family, Graminae and the most important cereal crops produced throughout the world. Wheat is believed to have originated in southwestern Asia (Gibson and Benson, 2002). It is one of the important staple foods in both developed and developing countries. As world population is increasing fast and estimated to reach over10 billion by 2050 and global insist for food is also increasing, producing additional wheat, is expected to become a high priority (Duveiller *et al.*, 2007; Gupta *et al.*, 2008a). The total production of wheat in the world is about 93,19,66,300 tons during 2017-18 and India produces about 99,61,008 tons from the 30,60,000 hectare of cultivated land (FAO, 2019-20). Wheat is attacked by several pathogens such as parasitic fungi, viruses, and nematodes and all are able of reducing yield significantly. Among all pathogens, fungi cause major losses and the stripe rusts are the most important diseases of wheat, causing major crop losses globally (Singh *et al.*, 2001). The three *Puccinia* species of rust fungi in wheat, *viz.*, *P. recondita* *P. graminis tritici* and *P. striiformis*, cause the most destructive diseases affecting wheat all over the world (Boyd, 2005; Kolmer, 2005; Hodson, 2011). Among three *Puccinia* of wheat, yellow rust and brown rust cause huge loss in northern India (van Ginkel and Rajaram, 1993). The disease occur in all wheat areas of the country and their occurrence depended up on environmental conditions, virulence and susceptibility of host at the time of disease onset (Roelfs *et al.*, 1992; Boyd, 2005). Stripe rust is restricted only in northern parts of the India, particularly in foot hills of Himalayas region. Spores of both, *P. recondita* and *P. striiformis* (yellow rust of wheat) are thought to be primarily dispersed by wind and rainfall, has the potential to spread both brown rust and yellow rust of wheat (Saari *et al.*, 1885). Rust diseases are responsible for massive economics losses in 1972-73, stripe rust which appears in epidemic form in Punjab, Haryana and western U.P., were responsible for a loss of nearly 0.9 to 1.5 million tones of wheat. In 1980, stripe rust epidemic in Uttar Pradesh and parts of Bihar caused a loss of 1 million tones of wheat. A number of strategies are available for the management of stripe rust diseases consisting of cultural, biological control, chemical seed treatment and spray of plant extracts, *etc*. However, rusts are foliar diseases on a single technique, effectively manage the rust disease like biological control and single use of fungicide method like bavistin, mancozeb and plantvax, causes environmental hazard or carcinogenic to the human; therefore, alternative approach IDM module reduced the risk of chemical and effective control of cereal rust diseases is possible mainly through employment of IDM modules (Brennan and Quade, 2004b).

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2. Materials and Methods

2.1 Collection of stripe rust samples

A total of 100 stripe rust samples were collected from randomly selected farmers' fields around Kanpur district of Uttar Pradesh. Stripe rust of wheat plants infected with rust pustules and were cut into small pieces of 8-11 cm, using scissors and placed in paper bags. The samples collected from Kanpur district of village Bilhaur (U.P.), India and these samples collected were kept in paper bags and tagged with the name of location and date of collection. The samples within the paper bags were air dried and kept in refrigerator at 12ºC until the collection in all districts were completed.

2.2 Multiplication and inoculation

The inoculum was multiplied and maintained on standard rust susceptible variety "Agra local" which does not carry any stripe rust resistant under polyhouse condition. 55 DAS plants are more suitable for multiplication of stripe rust of wheat or when the primary leaves were fully expanded and the second leaves beginning to grow. Small pieces of leaf sizes of 9-12 cm which are collected from the survey of farmers field have many urediospores of the stripe rust of wheat. These small pieces of leaf mix in the water (8-10 small pieces of leaf for 1000 ml water) methodically, after that sprayed on the "Agra local" cultivar of wheat under polyhouse condition from clean atomizer. For incubation, polyhouse maintain with dew chamber for 20 h dark period at 18-22ºC, followed by exposure to light for 4 h and 65-70 relative humidity to provide favorable condition for stripe rust infection. After 10 days of inoculation, symptoms were clearly visible on leaves, containing many urediospores and ready to inoculation to the strong plant with the help of leaf rubbing and atomizer method on pot experiment. Soon after inoculation of stripes rust on healthy plants under pot experiment, were placed in dark condition and transferred to a greenhouse following the earlier method mentioned above or covered with polybag.

2.3 Treatments

T_1 (Module I) = Soil application of *Tirchoderma harzianum* through farm yard manure, seed treatment with *Azotobactor*, 2 Sprays of zinc; 1st is crown root initiation stage, 2nd is booting stage. T_2 (Module II) = Soil application of *Azotobactor* through spent mashroom substrate, seed treatment with *Tirchoderma harzianum*, 2 Sprays of propiconazole; 1st is crown root initiation stage, 2nd is booting stage. T_3 (Module III) = Soil application of *Tirchoderma harzianum* through vermicompost seed treatment with *Tirchoderma harzianum*, 2 Sprays of neem extract; 1st is CRI stage, 2nd is booting stage. T_4 (Module IV) = Soil application of *Azotobactor* through vermicompost, seed treatment with *Tirchoderma harzianum*, 2 Sprays of tabuconazole; 1st is CRI stage, 2nd is booting stage. T_5 (Module V) = Soil application of neem cake, seed treatment with *Tirchoderma harzianum*, 2 Sprays of propiconazole; 1st is CRI stage, 2nd is booting stage. T_6 (Module VI) = Soil application of *Tirchoderma* through spent mushroom substrate, seed treatment with tabuconazole, 2 Sprays of neem extract; 1st is CRI stage, 2nd is booting stage, T_7 = Control (untreated).

2.4 Measurement of disease severity

Observations for measuring the disease severity were taken after 60 days, 80 days and 100 days after sowing. 10 leaves were randomly selected from each pot for measurement of disease severity. Observation on disease severity will be recorded using 0-4 scale (McIntosh *et al.*, 1995), The per cent disease severity will be calculated by following formula:

$$\text{Disease severity percentage} = \frac{\text{Sum of numerical ratings} \times 100 \text{ disease}}{\text{Number of plants scored} \times \text{maximum score on scale}}$$

Scale	Rating
O-	0-10% disease
1-	10-20% disease
2-	20-30% disease
3-	30-40% disease
4-	40-50%
5-	50-100%

2.5 Measurement of disease incidence

Observations for measuring the disease incidence were taken after 60 days, 80 days and 100 days after sowing. 12 leaves were randomly selected from each pot for measurement of disease severity, using following formula:

Disease incidence percentage

$$= \frac{\text{Total number of infected plant in pot}}{\text{Total number of plant examine}} \times 100$$

2.6 Statistical analysis

The data were analyzed by following the procedure of complete randomized design (CRD) and completely block design (CRD). Data recorded in percentage were first transformed at Arc Sin Value (Fisher and Yates, 1963). Treatments were compared by means of critical difference (CD) at 5 per cent level of significance.

3. Results

3.1 Variability significance of different modules on growth parameters of wheat at 80 DAS during 2018-19 and 2019-2020

Effect of IDM module on shoot length (cm) of wheat after inoculation of yellow rust at 80 DAS was studied under wire house condition in pot culture experiment. The observations of shoot length were taken at 80 days after sowing during 2018-19 and 2019-20. The data presented in Table 1, showed that in both the years, shoot length of wheat was increased in all the treatments over control. The maximum shoot length was recorded in T_1- S.A. of *Tirchoderma* through FYM, S.T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing (32.05 cm) and (34.00 cm) during 2018-19 and 2019-20, respectively. T_6-S.A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage. Shoot length was also increased, representing (28.30 cm) and (31.07 cm) during 2018-19 and 2019-20, respectively, followed by T_4-S.A.of *Azotobactor* through vermicompost, S. T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing (27.20 cm) and (30.60 cm) during 2018-19 and 2019-20, respectively. T_5- S.A. of neem cake, S. T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing (26.50 cm) and (30.50 cm) during 2018-19 and 2019-20, respectively. The shoot length significantly reduced was recorded in T_7-(Control), representing (22.50 cm) and (24.30 cm) during 2018-19 and 2019-20, respectively. The data presented in Table 1, showed that the root length significantly increased in comparison to all the treatments and control was recorded in T_1- S.A. of *Tirchoderma* through FYM, S.T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing (14.00 cm) and (16.50 cm) over control during 2018-19 and 2019-20, respectively (Table 1). After T_1, second highest root length was recorded in T_6-S.A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage, representing (11.50 cm) and (14.80 cm) during 2018-19 and 2019-20, respectively; followed by T_4-S.A. of *Azotobactor* through vermicompost, S.T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing (11.50 cm) and (12.60 cm) during 2018-19 and 2019-20, respectively and T_5-S. A. of neem cake, S.T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st is CRI stage, 2nd is booting stage, representing (09.50 cm) and (10.50 cm) during 2018-19 and 2019-20, respectively. The minimum root length was recorded in T_7-(Control), representing (07.50 cm) and (09.50 cm) during 2018-19 and 2019-20, respectively. Table 1 revealed that the maximum fresh weight of shoot was recorded in all the treatments over control, but highest fresh weight of shoot was found in T_1-S. A. of *Tirchoderma* through FYM, S.T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing 5.55 (g) and 5.80 (g) over control during 2018-19 and 2019-20, respectively. In T_6-S.A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage. The second highest fresh weight of shoot was recorded, representing 4.80 (g) and 4.89 (g) during 2018-19 and 2019-20, respectively, followed by T_4-S. A. of *Azotobactor* through vermicompost, S.T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing 4.29 (g) and 4.56 (g) during 2018-19 and 2019-20, repectively and T_5- S. A. of neem cake, S. T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 3.20 (g) and 4.40 (g) during 2018-19 and 2019-20, respectively. The minimum fresh weight of shoot was recorded in T_7- (Control) in comparison to all treatments, representing 2.16 (g) and 2.00 (g) during 2018-19 and 2019-20, respectively. The Table 1 data presented that the fresh weight of root was significantly increased in all the treatments over controls; however, maximum fresh weight of root was found in T_1-S.A. of *Tirchoderma* through FYM, S. T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing 1.92 (g) and 1.69 (g) during 2018-19 and 2019-20, respectively. In T_6-S. A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage and there was also significantly increase in fresh weight of root was recorded after T_1, representing 1.87 (g) and 1.54 (g) during 2018-19 and 2019-20, respectively; followed by T_4-S.A. of *Azotobactor* through vermicompost, S. T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing 1.40 (g) and 1.25 (g) during 2018-19 and 2019-20, respectively and T_5- S.A. of neem cake, S. T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 1.31 (g) and 1.10 (g) during 2018-19 and 2019-20, respectively. In T_7-(Control), minimum fresh weight of root was recorded over all treatments representing, 1.00 (g) and 1.01 (g) during 2018-19 and 2019-20, respectively. The data presented in Table 1 was recorded that the T_1-S.A. of *Tirchoderma* through FYM, S.T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, maximum dry weight of shoot over control, representing 2.31 (g) and 2.51 (g) during 2018-19 and 2019-20, respectively. Among all treatments, second highest dry weight of shoot was recorded in T_6 -S.A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage, representing 2.16 (g) and 2.40 (g) during 2018-19 and 2019-20, respectively; followed by T_4- S. A. of *Azotobactor* through vermicompost, S.T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing 2.20 (g) and 2.10 (g) during 2018-19 and 2019-20, respectively and T_5-S.A. of neem cake, S.T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 2.08 (g) and 2.13 (g) during 2018-19 and 2019-20, respectively. Minimum dry weight of shoot was recorded in T_7-(Control) in comparison to all treatments, representing 1.50 (g) and 1.10 (g) during 2018-19 and 2019-20, respectively. The Table 1 data show that the maximum dry weight of root was recorded in all the treatments over control; however, among all the treatments, maximum dry weight of root was recorded in T_1-S.A. of *Tirchoderma* through FYM, S. T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing 0.98 (g) and 1.60 (g) during 2018-19 and 2019-20, respectively. Among all the treatments, second highest dry weight of root was found in T_6-S. A. of *Tirchoderma* through spent mushroom substrate, S. T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage, representing 0.90 (g) and 1.42 (g) during 2018-19 and 2019-20, respectively; followed by T_4-S.A. of *Azotobactor* through vermicompost, S.T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing 0.78 (g) and 1.31 (g) during 2018-19 and 2019-20, respectively and T_5- S.A. of neem cake, S.T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 0.70 (g) and 1.10 (g) during 2018-19 and 2019-20, respectively. In T_7-(Control), in comparison to all treatments, show minimum dry weight of root, representing, 0.60 (g) and 0.70 (g) during 2018-19 and 2019-20, respectively. The data recorded in Table 1 show maximum number of tillers recorded in all the treatments in both the years over control, but among the all treatments, maximum number of tillers were recorded in T_1- S. A. of *Tirchoderma* through FYM, S. T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing 2.89 and 3.00 during 2018-19 and 2019-20, respectively. After T_1, the second highest number of tillers were recorded in T_6-S.A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage, representing 2.66 and 2.89 during 2018-19 and 2019-20, respectively, followed by T_4- S.A. of *Azotobacter* through vermicompost, S. T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing 2.54 and 2.45 during 2018-19 and 2019-20, respectively and T_5-S.A. of neem cake, S. T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 2.32 and 2.23 (g) during 2018-19 and 2019-20, respectively. Minimum number of tillers were recorded in T_7-(Control) in comparison to all treatments, representing 1.43 and 1.76 during 2018-19 and 2019-20, respectively.

Table 1: Effect of IDM module on plant growth parameters of wheat after inoculation of yellow rust at 80 DAS (Wire house condition) during 2018-19 to 2019-20

Treatment	2018-19							2019-20						
	Plant length (cm.)		Fresh weight (g)		Dry weight (g)		No. of tillers	Plant length (cm.)		Fresh weight (g)		Dry weight (g)		No. of tillers
	Shoot	Root	Shoot	Root	Shoot	Root		Shoot	Root	Shoot	Root	Shoot	Root	
T_1	32.05	14.00	5.55	1.92	2.31	0.98	2.89	34.00	16.50	5.80	1.69	2.51	1.60	3.00
T_2	24.40	8.14	3.15	1.29	1.80	0.86	1.63	25.90	11.70	3.28	1.08	2.00	1.00	1.88
T_3	25.10	10.10	3.58	1.20	2.02	0.66	2.00	27.01	12.10	5.50	1.11	2.10	1.10	2.03
T_4	27.20	11.50	4.29	1.40	2.20	0.78	2.54	30.60	12.60	4.56	1.25	2.10	1.31	2.45
T_5	26.50	09.50	3.20	1.31	2.08	0.70	2.32	30.50	10.50	4.40	1.10	2.13	1.10	2.23
T_6	28.30	11.50	4.80	1.87	2.16	0.90	2.66	31.07	14.80	4.89	1.54	2.40	1.42	2.89
(Control T_7)	22.50	07.50	2.16	1.00	1.50	0.60	1.43	24.30	09.50	2.00	1.01	1.10	0.70	1.76
SE (m)	0.496	0.478	0.185	0.034	0.046	0.024	0.072	0.621	0.717	0.214	0.046	0.069	0.037	0.119
SE (d)	0.701	0.676	0.262	0.049	0.066	0.034	0.102	0.878	1.013	0.303	0.066	0.097	0.052	0.168
CD at 5 %	1.437	1.385	0.536	0103	0.138	0.069	0.207	1.801	2.078	0.623	0.138	0.202	0.107	0.346

Mean of 5 replications *DAS = Day after sowing.

Table 2: Effect of IDM module on disease severity of wheat inoculation of yellow rust at different days interval (Wire house condition) during 2018-19 to 2019-20

Treatments	2018-19% Disease severity/pot				2019-20% Disease severity/pot			
	80 DAS	90 DAS	100 DAS	% Disease severity decrease over control	80 DAS	90 DAS	100 DAS	% Disease severity decrease over control
T_1	05.33	09.13	13.75	83.96	07.19	10.52	15.87	81.87
T_2	14.67	30.56	56.78	33.76	17.10	33.98	59.56	31.97
T_3	08.10	14.33	20.45	76.14	09.81	15.28	21.89	75.00
T_4	09.66	15.89	22.78	73.42	09.98	16.10	23.90	72.70
T_5	08.19	17.90	21.00	75.50	08.78	18.01	22.16	74.69
T_6	07.89	12.76	16.89	80.29	08.98	13.12	17.34	80.19
(Control) T_7	16.78	45.69	85.73	—	19.27	44.19	87.56	—
SE (m)	0.6739	0.8367	1.1952		0.8678	0.9562	1.5538	
SE (d)	0.9530	0.1830	1.6901		1.2270	1.3521	2.1970	
CD at 5 %	2.0780	0.4244	3.4635		2.5144	2.7708	4.5024	

Mean of 5 replications *DAS= Day after sowing.

Table 3: Effect of IDM module on disease incidence of wheat inoculation with yellow rust at different days interval (Wire house condition) during 2018-19 to 2019-20

Treatments	2018-19% Disease severity/pot				2019-20% Disease severity/pot			
	80 DAS	90 DAS	100 DAS	% Disease severity decrease over control	80 DAS	90 DAS	100 DAS	% Disease severity decrease over control
T_1	13.19	17.29	20.10	77.44	13.90	19.10	21.21	76.68
T_2	27.18	36.23	61.08	31.44	29.97	40.20	69.34	23.79
T_3	22.65	29.67	30.89	65.33	23.90	31.54	34.20	62.41
T_4	18.54	24.80	26.21	70.58	19.78	26.29	30.11	66.90
T_5	20.45	27.87	29.10	67.34	22.22	29.76	32.98	63.75
T_6	14.76	18.21	22.23	75.05	13.29	17.97	24.17	73.43
(Control) T_7	40.19	70.34	89.10	—	43.25	75.92	90.99	—
SE (m)	1.1116	1.4343	2.3905		1.2962	1.7928	2.9880	
SE (d)	1.5718	2.0281	3.3801		1.8329	2.5350	4.2251	
CD at 5 %	3.2209	4.1561	6.9268		3.7560	5.1951	8.6584	

Mean of 5 replications *DAS= Day after sowing.

Shoot parameter of wheat
root shoot parameters of wheat

T_1 (Module I) = S. A. of *Trichoderma* through FYM, S.T. with *Azotobacter* and 2 spraying of zinc, 1st is CRI stage, 2nd is booting stage.

T_2 (Module II) = S. A. of *Azotobacter* through SMS, S.T. with *Trichoderma* and 2 spraying of propiconazole, 1st is CRI stage, 2nd is booting stage.

(Module III) S. A. of *Trichoderma* through vermicompost, S. T. with *Trichoderma* and 2 spraying of neem extract, 1st is CRI stage, 2nd is booting stage.

T_4 (Module IV) = S. A. of *Azotobacter* through vermicompost, S. T. with *Trichoderma* and 2 spraying of tabuconazole, 1st is CRI stage, 2nd is booting stage.

T_5 (Module V) = S. A. of neem cake, S. T. with *Trichoderma,* 2 spraying of propiconazole, 1st is CRI stage, 2nd is booting stage.

T_6 (Module VI) = S. A. of *Trichoderma* through SMS S. T. with tabuconazole 2 spraying of neem extract, 1st is CRI stage, 2nd is booting stage.

Root shoot parameter of wheat

Disease severity of stripe rust

3.2 Variability significance of different modules on disease severity and incidence of yellow rust of wheat at different days of interval during 2018-19 to 2019-2020

The data presented in Table 2 showed that all the treatments significantly reduced disease severity of yellow rust of wheat as compared to control. However, among all the treatments, minimum disease severity was recorded in case of T_1-S.A. of *Tirchoderma* through FYM, S.T. with *Azotobacter*, 2 Sprays of zinc; 1st was CRI, stage 2nd was booting stage, representing 05.33%, 09.13% and 13.75% at 80, 90, and 100 days after sowing, respectively during 2018-19. Second lowest disease severity of yellow rust of wheat was recorded in T_6-S.A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage, representing 07.89%, 12.76% and 16.89% at 80, 90, and 100 days after sowing, respectively during 2018-19; followed by T_4- S.A. of *Azotobacter* through vermicompost, S.T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing 09.66%, 15.89% and 22.78% at 80, 90, and 100 days after sowing, respectively during 2018-19 and T_5-S.A. of neem cake, S.T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 08.19%, 17.90% and 21.00% at 80, 90, and 100 days after sowing, respectively during 2018-19. Highest disease severity was recorded in T_7- (Control), representing 16.78%, 45.69% and 85.73% at 80, 90, and 100 days after sowing, respectively during 2018-19. Percentage of highest decrease disease severity was found in T_1 83.96 % over control. Second highest decrease disease severity was recorded in T_6 80.29%; followed by T_4 73.42% and T_5 75.50% over control during 2018-19. The data presented in Table 2 showed that the disease severity of yellow rust of wheat in all treatments significan-tly reduced over control. However, among all the treatments, minimum disease severity was recorded in case of T_1-S.A. of *Tirchoderma* through FYM, S.T. with *Azotobacter*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing 07.19%, 10.52% and 15.87% at 80, 90, and 100 days after sowing respectively during 2019-20. After T_1, second minimum disease severity of yellow rust of wheat was recorded in T_6-S.A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage, representing 08.98%, 13.12% and 17.34% at 80, 90, and 100 days after sowing, respectively during 2019-20; followed by T_4-S.A. of *Azotobactor* through vermicompost, S. T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing 09.98%, 16.10% and 23.90% at 80, 90 and 100 days after sowing, respectively during 2019-20 and T_5-S.A. of neem cake, S.T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 08.78%, 18.01% and 22.16% at 80, 90, and 100 days after sowing, respectively during 2019-20. Among all the treatments, maximum disease severity was recorded in T_7-(Control), representing 19.27%, 44.19% and 87.56% at 80, 90, and 100 days after sowing, respectively during 2019-20. Among all the treatments, T_1 was more effective against and showed 81.87% disease severity over control. Second highest decrease disease severity was found in T_6 (74.69%) over control, followed by T_4 (72.70%) and T_5(74.69%) over control during 2019-20. The data presented in Table 3 showed that the disease incidence of yellow rust of wheat significantly reduced in all treatments over control. However, among all the treatments, minimum disease incidence was found in T_1-S.A. of *Tirchoderma* through FYM, S.T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing 13.19%, 17.29% and 20.10% at 80, 90, and 100 days after sowing, respectively during 2018-19. Among all the treatments, second effective treatment and lowest disease incidence of yellow rust of wheat was recorded in T_6-S.A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole; 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage, representing 14.76%, 18.21% and 22.23% at 80, 90, and 100 days after sowing, respectively during 2018-19; followed by T_4- S.A. of *Azotobactor* through vermicompost; S.T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd aws booting stage, representing 18.54%, 24.80% and 26.21% at 80, 90, and 100 days after sowing, respectively during 2018-19 and T_5- S. A. of neem cake, S. T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 20.45%, 27.87% and 29.10% at 80, 90, and 100 days after sowing, respectively during 2018-19. T_7- (Control) was not much effective against yellow rust of wheat; therefore, highest disease incidence was recorded in T_7- (Control), representing 40.19%, 70.34% and 89.10% at 80, 90, and 100 days after sowing, respectively during 2018-19. More effective treatment and maximum disease incidence was recorded in T_1(77.44%) over control. Second highest disease incidence in T_6(75.05%) over control, followed by T_4(70.58%) and T_5(67.34%) over control during 2018-19. The data presented in Table 3 showed that the disease incidence of yellow rust of wheat significantly reduced in all treatments over control. However, among all the treatments, highly effective and minimum disease incidence against yellow rust of wheat was recorded in T_1-S. A. of *Tirchoderma* through FYM, S. T. with *Azotobactor*, 2 Sprays of zinc; 1st was CRI stage, 2nd was booting stage, representing 13.90%, 19.10% and 21.21% at 80, 90, and 100 days after sowing, respectively during 2019-20. Among all the treatments, second more effective treatment and minimum disease incidence of yellow rust of wheat was found in T_6 -S. A. of *Tirchoderma* through spent mushroom substrate, S.T. with tabuconazole, 2 Sprays of neem extract; 1st was CRI stage, 2nd was booting stage, representing 13.29%, 19.10% and 21.21% at 80, 90, and 100 days after sowing, respectively during 2019-20; followed by T_4- S. A. of *Azotobactor* through vermicompost, S. T. with *Tirchoderma*, 2 Sprays of tabuconazole; 1st was CRI stage, 2nd was booting stage, representing 19.78%, 26.29% and 30.11% 80, 90, and 100 days after sowing, respectively during 2019-20 and T_5-S.A. of neem cake, S.T. with *Tirchoderma*, 2 Sprays of propiconazole; 1st was CRI stage, 2nd was booting stage, representing 22.22%, 29.76% and 32.98% at 80, 90, and 100 days after sowing, respectively during 2019-20. Highest disease severity was recorded in T_7-(Control), representing (43.25%), (75.92%) and (90.99%) at 80, 90, and 100 days after sowing, respectively during 2019-20. Per cent of highest decrease disease incidence against yellow rust of wheat was recorded in T_1(76.68%) over control. However, second highest decrease disease incidence was found in T_6(76.68%) over control, followed by T_4(66.90%) and T_5(63.75%) over control during 2018-19 (Table 3).

4. Discussion

IDM combining several method for the management of major diseases of wheat, the use of seed treatment, soil application of FYM and foliar application of neem seed extract (Singh and Rajaram, 1992a; McIntosh, 1992b). It can be defined as a decision-based process involving coordinated use of multiple tactics for optimizing the control of the pathogen ecologically and economically (Khokhar and Gupta, 2014). A investigation concluded that the fungicides propiconazole, with bioagents *T. harzianum* and botanicals (neem leaf extract and neem cake extract) in two season experiments were found to be effective in reducing the disease incidence, severity of brown and yellow rusts of wheat and increasing grain yield (Yadav *et al.*, 2015). Inoculation of bioagent increased wheat shoot fresh weight by 16.2%-53.8%, leaf area increases by 6.0%-47.0% and increased plant height by 2.2%-24.6% and 1.9%-36.8% in wheat (Cakmakcý *et al*., 2007). Seed treatment with bioagent which reduces disease severity and increase growth parameter should be done after treating the seeds with bioagent *T. harzianum viride* @ 4.0 g/kg seeds plus tebuconazole 2 DS (raxil) @ 0.1 g/kg of seeds (Goates and Jackson, 2006). It was found that seed treatment with fungicide plantvax @ 2.5 g/kg of seeds and use of balanced NPK fertilizers and spraying of plants with dithane M 45 @ 0.2% or propiconazole or tebuconazole @ 0.1% at 25-35 days interval starting from the first symptoms appearance in the field also reduced disease incidence and severity of wheat leaf rust (Ahanger *et al.*, 2014). Reported that sowing of seeds should be done after treating the seeds with bioagent *T. harzianum viride* @ 4.0 g/kg seeds plus tebuconazole 2 DS (raxil) @ 0.1 g/kg of seeds give excellent control of all three rust of wheat. Similarly, effect find out by Mehta, (2004) as IDM combining cultural, physical, chemical and biological methods for the management of wheat rust; the use of seed treatment, soil application of FYM and foliar application of neem seed extract. Application of fungicide solution of propiconazole and tebuconazole is recommended to control the yellow rust, but among these fungicides propiconazole (tilt) which gives excellent control of yellow rusts and is most effective when applied prior to infection (Eddy, 2009). A investigation concluded that the fungicides, propiconazole, carbendazim, tabuconazole with bio-agents *T. harzianum* and botanicals (neem leaf extract and neem cake extract) in two season experiments were found to be effective in reducing the disease incidence, severity of brown and yellow rusts of wheat and increasing grain yield (Kumar *et al.*, 2021; Chakraborty *et. al.*, 2021) reported that some secondary metabolites derived from *T. harzianum* inhibit mycelial growth, and conidial germination and produced morphological modifications in the germinated conidia, suppression of the several wheat diseases. Simon *et al.* (2021) found that effectiveness of different fungicides and biocontrol agent to control *Puccinia striiformis* reduced the disease severity in wheat against stripe rust

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Conflict of interest

The authors declare no conflicts of interest related to this article.

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