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The Effects of Fungicides and Bioagents on Rust (*Uromyces setaria*) Disease Management in Foxtail Millet

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ABSTRACT

Rust disease caused by *Uromyces Setaria* is a serious airborne disease of foxtail millet that causes a considerable reduction in grain yield under severe infection. An attempt was made to manage the rust disease using fungicides, natural formulations and bioagents under field conditions. The present investigation was undertaken at the Regional Agricultural Research Station (ANGRAU), Nandyal, Andhra Pradesh, India to evaluate different fungicides (six), natural formulations (two) and bioagent (one)for effective management of rust disease for three consecutive *rabi* seasons during 2018-19, 2019-20 and 2020-21. The experimental results indicated that the least percent disease index of 7.9 per cent was recorded with Hexaconazole (0.2%) and mean grain yield (1,585 kg/ha) with a 46.25 percent improvement in grain yield when compared with untreated control over three years of data. It was followed by 8.0 percent disease control achieved in continuous spray with Mancozeb at 10 days interval starting 30 days after sowing, which resulted in a 46.25 percent increase in grain yield (1,585 kg/ha) and Difenoconazole 25EC (Score @ 0.1 percent) with a percent disease index of 9.03 per cent and a 46.82 percent increase in grain yield (1,602 kg/ha). The natural formulations and bioagent has shown to be least effective in controlling rust disease compared to chemical fungicides, Among these, Neem seed Kernel Extract (5%) was found to be better with PDI of 25.1% compared other two treatments (Butter milk + Asafoetida and *Pseudomonas fluorescens* @10g/l. Two fungicides, *i.e* Difenoconazole and Hexaconazole were proven to be successful in reducing rust and offering marginal farmers in a cost-effective mode.The findings could aid in the development of rust management strategies in India, such as fungicide rotation and strategic fungicide treatment.

***Key words :** Bioagents, Fungicides, Foxtail Millet, Rust, PDI and Grain yield*

Introduction

Foxtail (*Setaria italica*L.) millet is cultivated as dry-land crop under marginal and sub- marginal lands of tropical and sub-tropical Asia. It is an important staple food for millions of people in southern Europe and Asia (Reddy *et al.,* 2006 and Hariprasanna, 2017). The grain is widely used as livestock and poultry feed. In India, foxtail millet was cultivated in an area of around 5 lakh ha which covers Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Uttar Pradesh, Gujarat and North Eastern states with an annual production of 2.9 lakh tonnes and productivity of around 600 kg/ha. Particularly in Andhra Pradesh foxtail millet was grown as rainfed crop during June-July and September - October and occupies in an area of 18000 ha with a production of 15 tonnes and productivity of 331 kg/ha (Crop and

Season Report, 2020-21). More specifically this crop is being cultivated in Ananthapuramu, Kurnool, Prakasam, Kadapa, Guntur and Vijayanagarm districts of Andhra Pradesh. In recent years, foxtail millet has gained popularity among people due to its high nutritional value and grain's higher level of vitamins and amino acids when compared to other cereal crops (Hou *et al.*, 2022).

Foxtail millet is infested by many diseases like blast, rust, brown leaf spot, downy mildewand smut. Among them, blast, rust and leaf spot are the major air-borne and most destructive diseases. Rust can cause significant crop yield reduction and it is caused by *Uromyces Setaria italica*, is known to be prevalent in all the states of India. Short-term epidemics are common and severe outbreaks can result in yield losses of 10-30% (Li *et al.*, 2015). The pathogen reduces grain yield and quality by consuming the plant's energy to grow, colonise, and reproduce inducing chlorosis and necrosis, which affect photosynthesis, light interception, and light reflectance; inducing rapid and widespread foliar senescence and poor grain filling. Early and heavy infection causes premature foliage drying, and the plants may dry up before heading. Depending upon the susceptibility of cultivar, earliness of initial infection, rate of disease development and duration of disease, the yield losses range between 10-70 per cent. Hence, the disease control practices are mostly required in order to prevent yield losses

Despite the fact that planting rust-resistant cultivars is the most effective and environmentally friendly way to reduce yield losses due to rust, the majority of foxtail millet production is based on susceptible varieties due to the emergence of new pathogenic races or pathotypes. In this context, research on chemical control is a top priority and fungicidal intervention is an effective and practical way to reduce disease outbreaks. Furthermore, using beneficial microbes to control rust infections could be a more environmentally friendly approach and reduce the potential risk of fungicide-resistance problem (Hou *et al.*, 2013). Given the current scenario, there is concern and a need for research on the proper application of fungicides and bioagents for foxtail millet rust control. Therefore, an attempt has been made to compare the efficacy of various fungicides and bioagents against rust in order to determine which is the most effective for rust management, as well as to investigate the impact of fungicides and bioagents on grain yield response, which could be used to improve rust disease management in endemic regions.

Materials and Methods

The experiment was carried out during *rabi* seasons of three consecutive years, 2018-19, 2019-20 and 2020-21 under natural epiphytotic conditions at the Regional Agricultural Research Station, ANGRAU, Nandyal, Andhra Pradesh, India. In each year, the trial was laid out in Randomized Block Design with three replications using rust susceptible foxtail millet variety, *i.e* Prasad. To achieve good crop growth, standard cultural and agronomic practices were adopted. Each entry was sown in a six rows plot of 3.0 m length and plot size of 3 m x 2.25 m, keeping 22.5 cm row to row and 10 cm plant to plant distance.

Six different fungicides *viz.,* Chlorothalonil (0.25%), Mancozeb (0.2%), Propiconazole (0.1%), Copperoxychloride (0.3%), Hexaconazole (0.2%), Difenoconazole (0.1%), two natural formulations *viz.,* NSKE (5%), Butter milk + Asafoetida and one bioagent *i.e Pseudomonas fluorescens* (10g/L) were evaluated for their effectiveness in controlling rust disease (Table 1). One more treatment *i.e* continuous spray of mancozeb at 10 days interval starting from 30 days after sowing was included and untreated control was maintained with water spray. Treatments were imposed immediately after the appearance of the rust disease. Periodic data on rust severity were also collected at fifteen-day intervals, starting with the initiation of the disease using 1-9 rating scale (Proceedings of 27th Annual Group Meeting of AICRP on Small Millets, 2016) as follows.

Incidence of rust: SES Scale

Score	Description
0 - 1	Pinhead flecks with no sporulation
1.1 - 3	Small scattered erumpent pustules with little sporulation
3.1 - 5	Clear many erumpent pustules containing numerous spores
5.1 - 7	Many coalescing pustules covering < 50% leaves
7.1 - 9	Many coalescing pustules covering most (>50%) leaves

At maturity, plots were individually harvested, threshed and grain yield per plot was recorded and then converted to kg/ha. The severity of the rust disease was graded on a 0-9 scale and the percent disease index (PDI) was derived using the formula below.

$$\text{Percent Disease Index (PDI)} = \frac{\text{Sum of numerical disease rating}}{\text{No. of plants observed}} \times \frac{100}{\text{Maximum disease grade}}$$

The economic return in the form of net income, benefit cost ratio was also calculated, considering actual cost of cultivation and fungicidal cost including labour charges for spraying. Data on PDI and grain yield (kg/ha) were analysed according to the analysis of variance procedure.

Results and Discussion

Numerous minute brown uredosori appeared on both the sides of the leaf. Rust pustules are oblong, brown, often formed in linear rows in 45 days after sowing. They were produced on the leaf lamina, leaf sheaths and culm. When the infection became severe, premature drying of leaves and poor grain set were observed. Symptoms of rust disease was observed and grades of disease severity were recorded. Bioefficacy of six different fungicides, two natural formulations, one bioagent and one additional treatment with continuous spray of mancozeb at 10 days interval starting from 30 days after sowing were evaluated against foxtail millet rust using Prasad cultivar during *rabi* season of three years 2018-19, 2019-20 and 2020-21 under natural epiphytotic conditions at the Regional Agricultural Research Station, ANGRAU, Nandyal, Andhra Pradesh, India, the results were pooled over seasons and are presented in Table 1.

Percent disease index of rust and grain yield performance during 2018-19

Minimum percent disease index of 6.3 % was observed in the treatment with Continuous spray of Mancozeb at 10 days interval starting from 30 Days after sowing and it was found effective in managing the disease followed by Hexaconazole @ 2ml/l (6.7%) and Difenoconazole @0.5 ml/l(6.7%) and these are on par with each other. All the treatments were significantly superior to untreated check (50.7%) except bioagent *Pseudomonas fluorescens* @10g/l which is having least effective with maximum percent disease index of 51.3 %. Highest grain yield of 1800 kg/ha was observed in treatment with

Table 1. Different fungicides, Bioagents in foxtail millet rust management

Treatments		Trade Name	Chemical group	Mode of action
T_1	Chlorothalonil (0.25%)	Kavach	Miscellaneous fungicide (Benzenes)	Non systemic, broad spectrum with multisite activity
T_2	Mancozeb (0.2%)	Dithane 75 WP	Monoalkyldithio carbamates	Interferes with enzymes containing sulphydryl groups
T_3	Propiconazole (0.1%)	Tilt 250 EC	Triazoles	C14 -demethylase in sterol biosynthesis
T_4	Copperoxychloride (0.3%)	Blitox	Copper fungicide	Non systemic, broad spectrum with protective activity
T_5	Hexaconazole (0.2%)	Contaf 5 EC	Triazoles	C14 demethylase in sterol biosynthesis
T_6	Difenoconazole (0.1%)	Score 250EC	Triazoles	C14 demethylase in sterol biosynthesis
T_7	NSKE (5%)	—	Neem	Anti-fungal
T_8	*Pseudomonas fluorescens* (10g/L)	Supplied by BC lab, Nandyal	Bio agent	Antibiosis/Induced systemic resistance
T_9	Butter milk + Asafoetida			Anti-fungal
T_{10}	1st Control Without any fungicidal spray			
T_{11}	2nd control Continuous spray of Mancozeb at 10 days interval stating from 30 Days after sowing			

Difenoconazole @ 0.5 ml/l with a yield superiority of 33.24 % over the untreated check followed by Hexaconazole @ 0.2 ml/l (1652 kg/ha superiority of 27.30 %) and Continuous spray of Mancozeb at 10 days interval starting from 30 Days after sowing (1631 kg/ha superiority of 26.32%) and these three treatments are on par with each other and significantly superior to rest of the treatments. Lowest grain yield of 915 kg/ha was recorded in *Pseudomonas fluorescens* (10g/l), representing an inferior performance of -31.26 % when compared to the untreated check (1201 kg/ha).

Percent disease index of rust and grain yield performance during 2019-20

A minimum percent disease index of 8.0 % was recorded in treatment with Hexaconazole (0.2%) and it was found effective in managing the disease followed by Continuous spray of Mancozeb at 10 days interval starting from 30 Days after sowing (8.0%) and Difenoconazole (0.1 %) (8.3%) and these are on par with each other. All the treatments were significantly superior to untreated check (53.0%) except bioagent *Pseudomonas fluorescens* (10 g/L) which is having least effective with maximum percent disease index of 56.7%. Highest grain yield of 1627 kg/ha was observed in treatment with Hexaconazole (0.2%) with a yield superiority of 60.66 % over the untreated check followed by continuous spray of Mancozeb at 10 days interval starting from 30 Days after sowing (1600 kg/ha superiority of 60.00 %) and Difenoconazole (0.1%)(1580 kg/ha superiority of 59.49%) and these three treatments are on par with each other and significantly superior to rest of the treatments. Lowest grain yield of 621 kg/ha was recorded in *Pseudomonas fluorescens* (10g/l), indicating an inferior performance of -3.06 % when compared to the untreated check (640 kg/ha).

Percent disease index of rust and grain yield performance during 2020-21

Minimum percent disease index of 9.0 % was recorded in the treatment with Hexaconazole @2ml/L and it was found effective in managing the disease followed by continuous spray of Mancozeb at 10 days interval starting from 30 Days after sowing (9.7 %) and Difenoconazole @0.5 ml/l (13.0 %) and these are on par with each other. All the treatments were significantly superior to untreated check (50.7 %) except bioagents *Pseudomonas fluorescens* @10g/l and Butter milk + Asafoetida, which were having least effective with maximum percent disease index of 57.7 % and 53.3 %, respectively. Highest grain yield of 1525 kg/ha was observed in the treatment with continuous spray of Mancozeb at 10 days interval starting from 30 Days after sowing with a yield superiority of 53.05 % over the untreated check followed by Hexaconazole @ 2ml/l (1476 kg/ha superiority of 51.49 %) and Difenoconazole @0.5 ml/l (1425 kg/ha superiority of 49.75 %) and these three treatments are on par with each other and significantly superior to rest of the treatments. Lowest grain yield of 653 kg/ha was recorded in *Pseudomonas fluorescens* @10 g/l, indicating an inferior performance of -9.65 % when compared to the untreated check (716 kg/ha).

Pooled percent disease index of rust and grain yield performance over *rabi* seasons during 2018-19, 2019-20 and 2020-21

Percent disease index and grain yield was pooled over three seasons revealed that, all the treatments resulted in reduced disease severity and increased harvest yield as compared to untreated control except bioagents where the disease severity was at par with the untreated control (Table 2). Among the different treatments applied for rust disease management, the maximum grade of disease severity over three years was recorded in the application of *Pseudomonas fluorescens* @10g/l (54.9 %)and it was 51.54% in untreated control. The per cent disease severity in *Pseudomonas fluorescens* application and untreated control was on par for two years *i.e* 2018-19 & 2019-20, where as in 2020-21 the per cent disease index was significantly varied among these two treatments and this difference may be due to maximum temperatures were observed during crop season due to which the bioagent may fail to get established . The minimum percent disease index of 7.9 % was recorded in treatment with Hexaconazole @ 2 ml/l followed by continuous spray of Mancozeb at 10 days interval starting from 30 Days after sowing (8.0 %) and Difenoconazole@ 0.5 ml/l (9.3 %) and these treatments were on par with each other.

Highest grain yield of 1602 kg/ha was observed in treatment with Difenoconazole @0.5ml/l with a yield superiority of 46.82 % over the untreated check followed by Hexaconazole @ 2 ml/l (1585 kg/ha with superiority of 46.25 %) and Continuous spray of Mancozeb at 10 days interval starting from 30 Days after sowing (1585 kg/ha superiority of 46.25 %) and these three treatments were on par with each other and significantly superior to rest of the treatments. Lowest grain yield of 730 kg/ha was recorded in *Pseudomonas fluorescens*@10g/l, representing an inferior performance of -16.71 % when compared to the untreated check (852 kg/ha).

In the present investigation, with the exception of bioagents, all fungicides reduced severity of disease and enhanced grain yield, while their effectiveness varied. This discrepancy in fungicide efficacy could be attributed to differing levels of internal tissue damage control by different products, which was not examined in this investigation. Several reports show the wide range of grain yield responses to fungicides used to control rust. Those values are influenced by a multitude of parameters, including the type of fungicide, application timing, number of applications, degree of rust susceptibility of the foxtail millet variety, environmental variables and application technology, to name a few.

Every year, epidemics have occurred in specific rust-prone regions where conditions are ideal for rust development. present findings show that even in years with minor outbreaks, cultivating susceptible cultivars can result in rust-induced grain yield losses. Late-sown rainfed and summer-grown foxtail millet are particularly prone to rust disease, which farmers primarily combat with fungicide sprays (Munirathnam *et al.,* 2015). In the present study, application of Difenoconazole (0.1%) resulted in nearly complete disease control and significant increase of 46.82 per cent in mean grain yield (1602 kg/ha). It was followed by Hexaconazole (0.2%) and Mancozeb at 10 days interval starting from 30 DAS, which increased the mean grain yield by 46.25 and 46.25 per cent, respectively, and offered superior yield than control. These observations are supported by theworks of Ashwani *et al.,* 2013; Sunilkumar Shirasangi *et al.,* (2017); Lokesh *et al.,* (2020) and Basamma Kumbar *et al.,* (2021) in different crops. Disease control by fungicide spray, can raise yields by up to 46.82 % and improved straw quality, which is commonly used as animal feed in India and other developing countries, could provide additional benefits. However, it is obvious that fungicides had a major impact in all cases where rust epidemics occurred, allowing farmers to limit or eliminate losses and produce improved yields in terms of grain number, weight, and quality of grain harvested (Narasimhudu *et al.,* 2006). The application of Mancozeb at 10 days interval starting from 30 DAS provided effective rust control. However, their use was limited due to the need to applyrepeatedly and because of their ineffectiveness against established diseases and higher cultivation costs.

In this study, economics were determined by considering the cost of cultivation, the cost of treatment, as well as gross and net returns. Difenoconazole (2.9) had the highest benefit-to-cost ratio, followed by Hexaconazole (2.8), which is on par with the Continuous spray of Mancozeb at 10-day intervals starting 30 days after sowing (2.8) and Propiconazole (2.6)(Fig. 1). New and effective fungicidal compounds, such as Difenoconazole and Hexaconazole, provided adequate rust control as well as higher grain yield over untreated control in an effective mode.

Conclusion

Rust can reduce foxtail millet grain yield signifi-

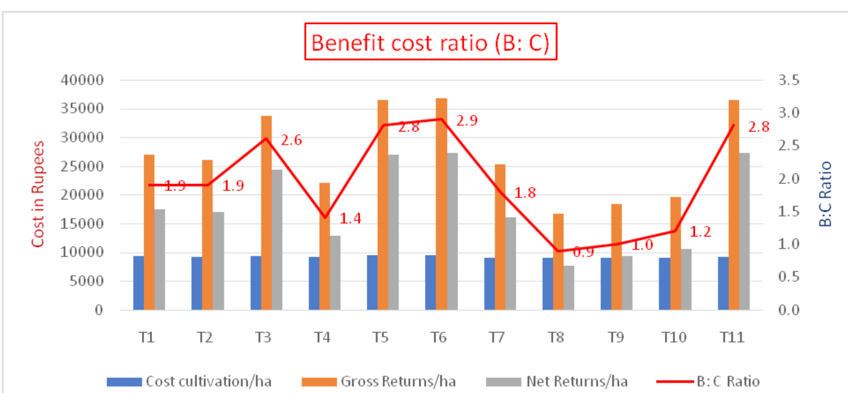

Fig. 1. Benefit cost ratio for Evaluation of different fungicides and bioagents for the management of foxtail millet rust Pooled over seasons.

Table 2. Efficacy of different fungicides and bioagents in rust management and their impact on grain yield of foxtail millet

	Treatments	2018-19			2019-20			2020-21			Pooled Mean		
		PDI	Yield (kg/ha)	Grain yield increas eover control (%)	PDI	Yield (kg/ha)	Grain yield increase over control (%)	PDI	Yield (kg/ha)	Grain yield increase over control (%)	PDI	Yield (kg/ha)	Grain yield increase over control (%)
T_1	Chlorothalonil (0.25%)	13.0 (21.1)	1,474	18.47	17.7 (24.8)	1,051	39.11	19.7 (26.3)	990	27.68	16.8 (24.1)	1,172	27.30
T_2	Mancozeb (0.2%)	20.7 (27.0)	1,513	20.62	22.3 (28.2)	921	30.51	24.2 (29.5)	975	26.56	22.4 (28.2)	1,136	25.00
T_3	Propiconazole (0.1%)	08.7 (17.1)	1,506	20.25	09.3 (17.8)	1,501	57.36	14.5 (22.4)	1,394	48.64	10.8 (19.1)	1,467	41.92
T_4	Copperoxychloride (0.3%)	27.0 (31.3)	1,293	7.04	27.6 (31.7)	880	27.27	32.3 (34.7)	714	-0.28	29.0 (32.6)	962	11.43
T_5	Hexaconazole (0.2%)	06.7 (15.0)	1,652	27.30	08.0 (16.4)	1,627	60.66	09.0 (17.5)	1,476	51.49	07.9 (16.3)	1,585	46.25
T_6	Difenoconazole (0.1%)	06.7 (14.9)	1,800	33.24	08.3 (16.7)	1,580	59.49	13.0 (21.1)	1,425	49.75	09.3 (17.6)	1,602	46.82
T_7	NSKE (5%)	21.7 (27.7)	1,523	21.14	24.4 (29.6)	910	29.67	29.3 (32.8)	861	16.84	25.1 (30.0)	1,098	22.40
T_8	*Pseudomonas fluorescens* (10g/L)	51.3 (45.5)	915	-31.26	56.7 (48.9)	621	-3.06	57.7 (49.4)	653	-9.65	54.9 (47.8)	730	-16.71
T_9	Butter milk + Asafoetida	49.3 (44.6)	928	-29.42	52.3 (46.4)	680	5.88	53.3 (46.9)	788	9.14	51.6 (46.0)	799	-6.63
T_{10}	1st Control Without any fungicidal spray	50.7(45.4)	1,201	0.00	53.0 (46.7)	640	0.00	50.7 (45.4)	716	0.00	51.5 (45.8)	852	0.00
T_{11}	2nd control Continuous spray of Mancozeb at 10 days interval stating from 30 Days after sowing	06.3 (14.5)	1,631	26.32	8.0 (16.5)	1,600	60.00	09.7 (18.1)	1,525	53.05	08.0 (16.4)	1,585	46.25
	Mean	23.7	1403		26.1	1092		28.5	1047		26.1	1181	
	Min	6.3	915		8.0	621		9.0	653		7.9	729	
	Max	51.3	1800		56.7	1627		57.7	1525		54.9	1602	
	SeM±	1.07	58.81		0.88	57.67		0.91	89.90		0.88	75.96	
	CD 5%	3.17	173.5		2.60	170.14		2.68	265.21		2.60	224.08	
	CV %	6.74	7.26		5.84	9.15		5.04	14.87		5.85	11.14	

* Values in parenthesis transformed values

cantly in susceptible cultivars, hence using fungicides to manage the disease under epiphytotic conditions is recommended. For rust management, a wide range of commercial fungicide formulations containing a single or multiple active components in a mixture are currently approved and/or recommended in all foxtail millet growing regions in India. The usage of fungicides from the demethylation inhibitors (DMI) groups should be incorporated into management strategies for effective rust control. Among all the treatments, chemical fungicides were found effective in control of rust disease compared to natural formulation and bioagent application. Among chemical fungicides, Hexaconozole was most effective in decreasing per cent disease index of rust compared to control, although it was on par with Difenoconozole and Continuous spray of Mancozeb at 10 days interval stating from 30 Days after sowing. The results highlight the important information about selection of fungicides and spray concentrations to control rust. Such data, which is currently unavailable, could be useful in developing a comprehensive foxtail millet rust management strategy.

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