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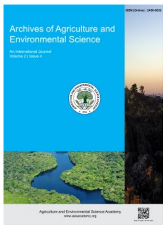

ORIGINAL RESEARCH ARTICLE

Integrated approach for the management of common bean rust (*Uromyces appendiculatus*) under field conditions

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ABSTRACT

A field experiment was conducted to test the efficacy of different management practices and fungicide application timings for common bean rust management in Chitwan, Nepal. It was conducted in a randomized complete block design (RCBD) with two factors: management practices (Azoxystrobin, *Trichoderma viride*, maize intercropping + *Trichoderma viride*, Neem + Garlic extracts, and inoculated and untreated controls) and fungicide application timings (8 days after inoculation and 3 days after inoculation), each with three replications. The minimum disease severity was found with azoxystrobin, which was at par with neem + garlic extract and maize intercropping + Trichoderma at 50 days after inoculation (DAI). The maximum number of rust pustules per cm^2 was observed in the control plots (7.56), followed by Trichoderma (4.79) at 50 DAI. The maximum necrotic colonies (%) were observed with the control (36.88%), followed by Trichoderma (25.15%), while the effects of other treatments were at par at 40 DAI. Maize intercropping with Trichoderma resulted in a maximum plant height (201.56 cm), which was at par with azoxystrobin (197.81 cm). The plants treated with azoxystrobin showed maximum green pod yield at one picking (2411.35 g) which was at par with maize intercropping + Trichoderma and neem + garlic extracts. Rust was controlled more effectively when the fungicides were sprayed at 4 DAI than 8 DAI. The maximum disease control was observed with Azoxystrobin; however, as other treatments also had comparable effects, an integrated approach could be adopted for the sustainable management of common bean rust.

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INTRODUCTION

The common bean (*Phaseolus vulgaris* L.), which is also called French bean, kidney bean, snap bean, or navy bean, belongs to the family Leguminosae and is an important grain legume crop. The primary centers of origin are southern Mexico and Central America, while Peruvian Equadorian-Bolivian areas are considered secondary centers (Thompson and Kelly, 1957). It is grown for tender green pods and dry beans. Its tender green pods are used as a vegetable, while its dry grains are used as a pulse. According to the growth habits, there are two types: pole-type and bush-type. Pole-type varieties are tall, indeterminate in growth, and require support. Bush-type varieties are dwarf and are more popular because of their compactness, ease of harvest, and short duration (60-70 days). The green pods are rich in calcium, protein, phosphorus, and iron. The seeds are rich in protein. Common bean rust, incited by *Uromyces appendiculatus*, is a widespread disease that occurs in almost all bean-producing regions, including Nepal. Uredospores are repeating spores and are light brown, unicellular, thin-walled, echinulate, and globoid or ellipsoid in shape, as shown in Figure 1. Cummins (1978) reported that they have two equatorial or superequatorial spores and measure 20-27 µm × 24-30 µm. In case of severe infection, leaves curl upward, dry up, turn brown, leaf area decreases, and premature defoliation can be observed (Schwartz, 1984). Sometimes pustules can be seen on stems and branches, and rarely on green pods.

Rust causes significant yield loss of beans in humid tropical and subtropical regions where the temperature ranges between 17 and 23 °C (Alzate-Marin *et al.*, 2004; Pastor-Corrales and Liebenberg *et al.*, 2010). Acevedo *et al.* (2013) reported a 50% yield loss, but it may be 100% depending on the earliness and the severity of the infection. Lindgren *et al.* (1995) reported that a one percent increment in disease severity measured at 72-75 days after sowing (DAS) caused about 19 kg of yield loss per hectare. A study conducted by De Jesus Junior *et al.* (2001) revealed a four-fold reduction in common bean yield due to rust as compared to angular leaf spot. Raggi (1980) revealed that infection causes an alteration in the physiological function of bean leaves as respiration increases while photosynthesis decreases. It is a chronic yield-limiting disease and causes serious havoc in common bean production worldwide (Stavely and Pastor Corrales, 1989). Currently, it is a major problem for commercial bean production in Chitwan as well as in the whole of Nepal. The declining trends in the production and area of cultivation of common beans in Nepal can be attributed to this disease.

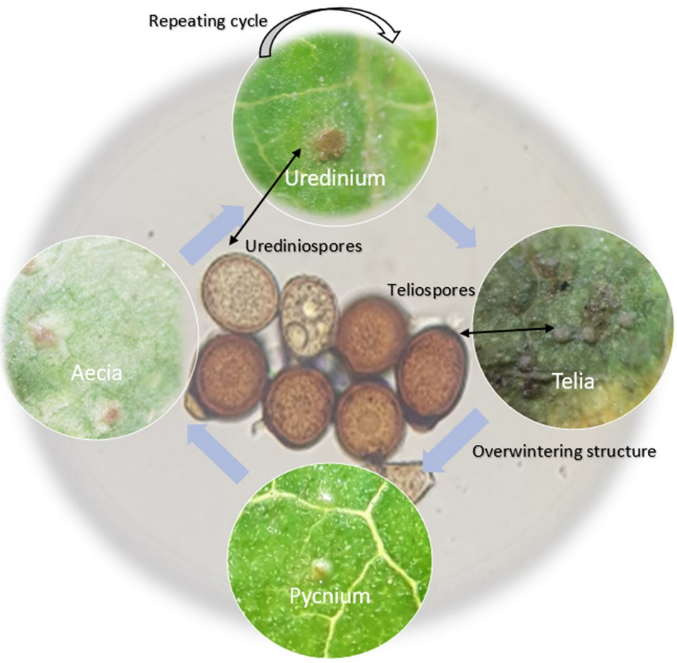

Figure 1. *Disease cycle of U. appendiculatus.*

Several management practices were recommended for the control of bean rust. Common recommendations were the application of chemical fungicides and the development of resistant cultivars. The excessive use of chemical fungicides has caused several negative impacts on the health of the environment and even humans and also increases production costs (Arslan *et al.*, 2006; Bhandari *et al.*, 2021). Moreover, it has developed resistance in many fungi species. Similarly, the development of resistant varieties is not a sustainable approach in the management of fungal diseases as pathogens break resistance over time (Yuen *et al.*, 2001). The wide variability of *Uromyces appendiculatus* is the major constraint for the development of durable resistant varieties for plant breeders (Souza *et al.*, 2013). It is impossible and ineffective for the complete management of bean rust by using only one method (Surviliene and Dambrauskiene, 2006). The application time of fungicides plays a crucial role in the germination of conidia and host penetration, and ultimately in the development of disease. It is an important factor in increasing the efficacy of the applied fungicides. However, very limited research articles have been published that evaluate integrated management practices and application timings of fungicides for the control of common bean rust. Thus, the rationale of this research is to analyze the efficacy of different management practices and application timings of fungicides to develop the appropriate approaches for the sustainable management of common bean rust.

MATERIALS AND METHODS

Description of the experimental site

The study was conducted in the farmer's field at Bhatarpur-29, Jugedi, Chitwan, from March to May 2022. It is located at 27° 45' 27.42" N latitude and 84° 28' 25.33" E longitude, with an elevation of 291 m above sea level (masl) (Mapcarta, 2022). The soil sample was analyzed in the soil laboratory of the Agriculture and Forestry University, Rampur, Chitwan. Nitrogen content was medium, phosphorus and potassium content were low, and pH was 6.5.

Experimental design and details of the treatment used

The experiment was conducted in a randomized complete block design (RCBD) with two factors and three replications. The first factor was fungicide application timings, i.e., 4 days after inoculation (DAI) and 8 DAI, and the second was management practices, i.e., bean and maize intercropping (4:3 ratio) + *Trichoderma viride* @ 5ml/l water, *Trichoderma viride* at 5 ml/l water, neem + garlic extract (50%) (1:1 ratio) at 6 ml/l water each, Azoxystrobin at 0.1%, and the control. The individual plot size was 3.6 m^2(2.4m×1.5m) and the area of the research field was 255 m^2 (25.5m×10m). Inter-block and inter-plot spacing were 1m each.

Horticultural practices

A rust susceptible variety of French beans (Italy-38) was planted for the experiment. It is a pole-type variety of the common bean.

The fertilizers such as nitrogen, phosphorus, and potassium were applied at the recommended rates of 80 kg, 120 kg, and 60 kg per ha in the form of urea, DAP, and MOP as basal doses. The seeds were sown at a spacing of 80×50 cm^2. The first weeding was done at 15 DAS, and subsequent weddings were performed before the day of irrigation at 34 DAS and 59 DAS.

Preparation of uredospore suspension and its inoculation

A suspension of uredospores from a single isolate of the fungus was prepared in distilled water and stored at 4°C before use. The suspension of uredospores was standardized by using a hemocytometer in the pathology lab of Agriculture and Forestry University. The standardized solution was diluted to the final concentration of 10^5 spores per ml water at the time of spray and mixed with 0.1g of agar per liter water (Sackston, 1960). The pathogen was inoculated after the second trifoliate leave appeared at 30 DAS (Mersha and Hau, 2008) through foliar application by mixing with sticker 'Tasin' at 1ml/2l water.

Preparation and spray of botanical fungicides

Neem extract and garlic extract in a ratio of 1:1 were used as botanical fungicides. Neem leaves were dried in the sun for five days and ground into a mixture. 50 g of grounded leaves were mixed with 300 ml of distilled water and kept as such for 24 hours. The supernatant was strained with a muslin cloth and centrifuged at 3000 rpm for 15 minutes (Al Charchafchi, 2007). That was with a concentration of 100%. Later, it was diluted to 50% at the time of application. For the extraction of garlic, it was first peeled, and 100 g of it was ground in a grinder with 100 ml of distilled water. The filtrate was later diluted to 50% at the time of application. The fungicide solutions were mixed with sticker (Tasin) before each spray for their effectiveness. Fungicides were sprayed in half of the plots 4 days after inoculation and in the remaining half 8 days after disease inoculation, according to the pre-designed experimental methods.

Measurement

Five plants from each plot were tagged randomly and used for the study. From the tagged plants, three leaves, one from each lower, middle, and top layer were randomly selected for non-destructive sampling (Habtu and Zadoks, 1994).

Disease severity

Disease scoring was done by using a diagrammatic scale given by Godoy *et al.* (1996). Based on this, disease severity was estimated by using the following formula developed by Sharma and Kolte (1994).

$$\text{Disease severity (\%)} = \frac{\text{The sum of all numerical ratings}}{\text{Total number of plants observed} \times \text{maximum rating}} \times 100$$

Disease severity was recorded four times at 20, 30, 40, and 50 days after inoculation (DAI).

Number of rust pustules/cm^2

Data on the number of rust pustules/cm^2 was taken at 20, 30, 40, and 50 DAI. A square-shaped frame of 25 cm^2 was used and was held on the leaves to be sampled. The number of pustules lying within that frame was counted and later those numbers were divided by 25 to obtain pustules/cm^2.

Percentage of rust colony with necrosis

The rust colony having necrosis on the leaf surface was counted and its percentage was calculated by using the following formula:

$$\text{Percentage colony with necrosis} = \frac{\text{Number of rust colonies with necrosis}}{\text{Total number of rust colony}} \times 100$$

Area Under Disease Progress Curve (AUDPC)

The AUDPC was calculated using the following formula as previously used by Das *et al.* (1992).

$$AUDPC = \sum_{i=1}^{n} (Y_{i+1} + Y_i)\, 0.5\, (T_{i+1} - T_i)$$

Where Y_i = disease severity on the i^{th} date
T_i = date on which the disease was scored
n = number of dates on which the disease was scored

Statistical analysis

Data were entered in MS EXCEL. R-studio of version 4.1.2. was used for the data analysis. Ducan's Multiple Range Test (DMRT) was employed to find out the significant differences between the mean values at a 5% level of significance.

RESULTS AND DISCUSSION

Disease severity test of leaves

In all the management practices, disease severity increased with plant age and significantly differed among the treatments, as shown in Table 1. At 20 days after inoculation (DAI), the effect of all the treatments was found to be significantly greater against disease severity than control. The highest disease severity was found in the control plot. The effect of management practices was statistically at par. The effect of the fungicide application timings on disease severity was statistically insignificant. At 30 DAI, all the treatments were found to be statistically more effective against disease severity than the control at a 0.1% level of significance but were at par with each other. The effect of fungicide application timings on the disease severity of bean leaves was found to be insignificant. At 40 DAI, the highest disease severity was found in the control plot. The least disease severity was shown by azoxystrobin, which was at par with maize intercropping + Trichoderma and neem + garlic extract. In a study conducted by Devi (2020), four applications of azoxystrobin (0.1%) at 10-day intervals resulted in only 3.81% rust severity in common beans, which was similar to our study. In an in vivo experiment, Sharma *et al.* (2018) also found the lowest rust severity (4.64%) with azoxystrobin (0.1%) on the bean. The highest disease severity was in the plots that were sprayed at 8 DAI.

Table 1. Effects of different management practices and fungicide application timings on disease severity of common bean rust.

	Treatment	Disease severity (%)			
		20DAI	30DAI	40DAI	50DAI
Application timings					
	4 DAI	2.97	5.13	10.51[b]	29.72[b]
	8 DAI	2.82	4.75	14.12[a]	32.73[a]
	SEm (±)	0.34	0.53	0.85	0.96
	F-test	NS	NS	**	*
	LSD	1.006	1.56	2.53	2.87
Management practices	Maize intercropping +Trichoderma	2.33[b]	3.97[b]	9.84[bc]	30.29[bc]
	Trichoderma	3.04[b]	5.49[b]	13.31[b]	34.46[b]
	Neem+garlic extract (1:1)	2.17[b]	2.93[b]	11.92[bc]	26.23[c]
	Azoxystrobin	1.84[b]	3.07[b]	8.60[c]	19.26[c]
	Control	5.12[a]	9.22[a]	17.90[a]	45.68[a]
	SEm (±)	0.54	0.83	1.35	1.53
	F-test	**	***	**	***
	LSD	1.59	2.47	2.97	2.97
	C.V. %	45.17	41.29	26.81	12.02
	Grand mean	2.90	4.94	12.31	31.22

[Note: DAI: Days after inoculation, CV: Coefficient of variation, LSD: Least significant difference: Means followed by the same letter in a column are not significantly different by DMRT at 5% level of significance, SEm(±): Standard error of mean, ***: significant at 0.001, **: significant at 0.01 and *: significant at 0.05 level, NS: Not-significant].

Table 2. Effects of different management practices and fungicide application timings on the number of rust pustules per cm^2 on leaves of common bean.

	Treatment	Number of pustules per cm^2 on leaves			
		20DAI	30DAI	40DAI	50DAI
Application timings					
	4DAI	0.85	1.53	2.47[b]	3.82[b]
	8DAI	0.92	1.66	3.01[a]	4.58[a]
	SEM (±)	0.14	0.16	0.10	0.11
	F-test	NS	NS	*	***
	LSD	0.41	0.48	0.30	0.33
Management practices	Maize intercropping+Trichoderma	0.61[b]	1.72[bc]	2.32[c]	3.94[c]
	Trichoderma	0.95[b]	1.64[b]	2.89[b]	4.79[b]
	Neem+garlic extract (1:1)	0.44[b]	0.98[bc]	1.93[c]	2.77[d]
	Azoxystrobin	0.31[b]	0.65[c]	1.38[d]	1.93[e]
	Control	2.26[a]	3.53[a]	5.15[a]	7.56[a]
	SEM (±)	0.22	0.26	0.16	0.17
	F-test	***	***	***	***
	LSD	0.65	0.48	0.48	0.53
	C.V.%	58.89	39.75	14.63	10.42
	Grand mean	0.91	1.59	2.73	4.20

[Note: DAI: Days after inoculation, CV: Coefficient of variation, LSD: Least significant difference: Means followed by the same letter in a column are not significantly different by DMRT at 5% level of significance, SEm(±): Standard error of mean, ***: significant at 0.001, **: significant at 0.01 and *: significant at 0.05 level, NS: Not-significant].

At 50 DAI, the application of *Trichoderma viride* also showed significantly less disease severity than the control, which is supported by the study conducted by Iamail and Afifi (2019). The effect of azoxystrobin was statistically at par with maize intercropping with Trichoderma and neem with garlic extract. The maize plant might act as a sort of barrier for wind-blown spores from other plots to reach the maize intercropped plot and also within the same plot, thereby reducing the amount of inoculum (Shyata *et al*., 2021).

Number of rust pustules per cm^2 on leaves of common bean

The number of pustules per cm^2 on leaves was significantly influenced by different management practices at all dates of observations, while a significant effect of fungicide application timings was seen at 40 and 50 DAI, as shown in Table 2. At 20 DAI, the control plot showed the significantly highest number of pustules per cm^2 on leaves, while all the other management practices had similar effects on it. At 30 DAI, the statistically highest number of pustules per cm^2 on leaves was found in the control. The effects of the maize intercropping + Trichoderma, Trichoderma, and neem + garlic extract were statistically at par. The least number of pustules per cm^2 on leaves was found in the plot treated with azoxystrobin, which was at par with the botanical treatment. At 40 DAI, the highest number of pustules per cm^2 was observed in the control (5.15), followed by the Trichoderma-treated plots (2.89). The reduction in rust severity with the application of antagonistic fungi is attributed to inhibition in spore germination, inhibition in enzyme production by the pathogen, induced systemic resistance, and the production of antimicrobial toxins (Ismail, 2019).

Table 3. Effects of different management practices and fungicide application timings on the percentage of the rust colony with necrosis on leaves.

	Treatment	Necrotic colonies (%)			
		20DAI	30DAI	40DAI	50DAI
Application timings					
	4DAI	3.92	6.30^{b}	15.21	25.26^{b}
	8DAI	4.69	7.99^{a}	20.71	32.01^{a}
	SEM (±)	0.52	0.54	1.93	1.20
	F-test	NS	*	NS	***
	LSD	1.55	5.14	5.74	3.57
Management practices	Maize intercropping+Trichoderma	3.58^{bc}	6.91^{bc}	12.05^{c}	19.77^{c}
	Trichoderma	5.41^{b}	8.64^{b}	24.15^{b}	34.11^{b}
	Neem+garlic extract (1:1)	2.82^{c}	5.02^{cd}	11.22^{c}	17.86^{c}
	Azoxystrobin	1.36^{c}	2.60^{d}	5.50^{c}	10.77^{d}
	Control	8.36^{a}	12.55^{a}	36.88^{a}	60.67^{a}
	SEM (±)	0.83	0.85	3.05	1.90
	F-test	***	***	***	***
	LSD	2.45	2.97	9.07	5.65
	C.V.%	47.02	59.32	41.65	16.27
	Grand mean	4.31	7.14	17.96	28.63

[Note: DAI: Days after inoculation, CV: Coefficient of variation, LSD: Least significant difference: Means followed by the same letter in a column are not significantly different by DMRT at 5% level of significance, SEm(±): Standard error of mean, ***: significant at 0.001, **: significant at 0.01 and *: significant at 0.05 level, NS: Not-significant].

Table 4. Effects of different management practices and fungicide application timings on yield and yield attributing parameters (pod length, pod yield in one picking, and fresh biomass) of common bean.

	Treatment	Yield and yield attributing parameters		
		Pod length (cm)	Pod yield (kg/ ha) in one picking	Fresh biomass (g/ plant)
Application timings				
	4DAI	13.97^{a}	2237.71^{a}	138.0
	8DAI	13.33^{b}	1967.13^{b}	126.9
	SEM (±)	0.15	38.91	5.37
	F-test	**	***	NS
	LSD	0.45	115.59	25.20
Management practices	Maize intercropping+Trichoderma	14.72^{b}	2297.15^{ab}	165.0^{a}
	Trichoderma	13.69^{c}	2167.36^{b}	113.41^{b}
	Neem+garlic extract (1:1)	14.42^{b}	2263.14^{ab}	123.16^{b}
	Azoxystrobin	16.67^{a}	2411.35^{a}	172.91^{a}
	Control	8.76^{d}	1373.11^{c}	87.75^{c}
	SEM (±)	0.24	61.52	8.49
	F-test	***	***	***
	LSD	0.72	182.77	25.20
	C.V.%	4.36	7.16	15.68
	Grand mean	13.65	2102.42	132.45

[Note: DAI: Days after inoculation, CV: Coefficient of variation, LSD: Least significant difference: Means followed by the same letter in a column are not significantly different by DMRT at 5% level of significance, SEm(±): Standard error of mean, ***: significant at 0.001, **: significant at 0.01 and *: significant at 0.05 level, NS: Not-significant].

The effects of maize intercropping with Trichoderma and neem with garlic extract were statistically at par. Statistically, the least number of pustules per cm^2 was found with azoxystrobin (0.1%), which is consistent with the findings of Sharma *et al.* (2018). The number of pustules per cm^2 was found to be significantly higher when fungicides were sprayed at 8 DAI (3.01) as compared to when sprayed at 4 DAI (2,47). At 50 DAI, all the management practices had significantly different effects on the number of pustules per cm^2. The maximum number of pustules was observed in the control (7.56), followed by Trichoderma (4.79), maize intercropping + Trichoderma (3.94), neem + garlic extract (2.77), and azoxystrobin (1.93). The number of pustules per cm^2 was found significantly less when the fungicides were sprayed at 4 DAI than at 8 DAI at a 0.001 level of significance. This was because the uredospore got comparatively more time for germination and host penetration when the fungicides were sprayed at 8 DAI as compared to 4 DAI.

Percentage of rust colonies with necrosis on leaves

The management practices had a significant influence on the percentage of rust colonies with necrosis at all dates of observations, while the fungicide application timings had an influence on 30 DAI and 50 DAI, as presented in Table 3. At 20DAI, the highest percentage of the colony with necrosis was observed in the control (8.36%), followed by the Trichoderma-treated plots (5.41). Maize intercropping + Trichoderma (3.58%), neem + garlic extract (2.82%), and azoxystrobin (1.36%) had statistically similar effects on the percentage of the colony with necrosis. At 30 DAI, the control plots showed the maximum percentage of the colony with necrosis (12.55%). It was followed by Trichoderma (8.64%) and maize intercropping + Trichoderma (6.91%), which were statistically similar. The lowest percentage of rust colonies with necrosis was found with azoxystrobin (2.60%) and neem and garlic extract (5.02%) which were also statistically at par. Garlic contains bioactive chemicals called allicin, which delays and inhibits spore germination in fungi (Lengai *et al*., 2020). The inhibition of uredospore germination with neem extract was also observed by Devi *et al*. (2019), which is due to the phenolic compound quercetin. The percentage of colonies with necrosis was found to be significantly higher when fungicides were sprayed at 8 DAI (7.99%) than those sprayed at 4 DAI (6.30%). At 40 DAI, control plots showed the maximum percentage of the colony with necrosis (36.88%), followed by Trichoderma (24.15%). The effect of other management practices was found to be statistically similar. At 50DAI, the maximum percentage of rust colonies was found in the control (60.67%), followed by Trichoderma (34.11%). The effect of maize intercropping with Trichoderma and neem with garlic extract was statistically similar. The lowest percentage of colonies with necrosis was observed in the azoxystrobin-sprayed plot (10.77%), which is similar to the results of Sharma *et al*. (2018) and Devi (2020). Fungicides sprayed at 8 DAI (32.01%) showed a significantly higher percentage of colonies with necrosis than those sprayed at 4 DAI (25.26%).

Yield and yield-attributing parameters

Yield and yield attributing parameters such as pod length, pod yield, and fresh biomass were recorded and found statistically significant with different management practices, as shown in Table 4. The fungicide application timings had a significant impact on pod length and pod yield. The maximum pod length was found with azoxystrobin (16.67 cm). The maximum green pod yield with azoxystrobin (0.1%) was also reported by Sharma *et al*. (2018). The impact of maize intercropping with Trichoderma (14.72 cm) and neem and garlic (14.42 cm) extracts was similar. The lowest pod length was observed with the control (8.76 cm). The yield of the green pod in one picking was found to be maximum with azoxystrobin (2411.35 kg/ha), which was at par with neem + garlic extract and maize intercropping + Trichoderma. The lowest pod yield was observed in the control (1373.11 kg/ha). The highest fresh biomass was observed in the azoxystrobin-treated pots (172.91 g/plant). Fresh biomass was found to be higher with maize intercropping + *Trichoderma* (165 g/plant) than *Trichoderma* (113.41 g/plant) alone. It was because, besides being a bio-fungicide, *Trichoderma viride* also acts as a biofertilizer (Bhandari *et al*., 2021), and maize plants might have provided a favorable microclimate for bean growth. The pod length (13.97 cm) and pod yield (2237.71 kg/ha) were found to be significantly higher when fungicides were sprayed at 4 DAI as compared to when they were sprayed at 8 DAI.

Correlation test

There were significant correlations between different parameters observed, as shown in Table 5. Disease severity had a significant positive correlation with other disease parameters such as rust pustules/cm^2 and necrotic colonies, while there was a negative correlation with the growth and yield parameters. The same case was observed for other disease parameters. The plant height had a positive correlation with the yield parameters and a negative correlation with the disease parameters.

Table 5. Pearson's correlation coefficient between different disease parameters, growth parameters, and yield parameters.

	Disease severity (%)	Rust pustules/ cm^2	Necrotic Colonies (%)	Plant height (cm)	Fresh biomass (g)	Pod length (cm)	Pod yield (kg/ha)
Disease severity (%)	1						
Rust pustules/cm^2	0.926***	1					
Necrotic Colonies (%)	0.914***	0.912***	1				
Plant height (cm)	-0.811***	-0.775***	-0.803***	1			
Fresh biomass (g)	-0.739***	-0.631***	-0.732***	0.724***	1		
Pod length (cm)	-0.802***	-0.787***	-0.879***	0.618***	0.743***	1	
Pod yield at one picking	-0.859***	-0.914***	-0.882***	0.789***	0.674***	0.768***	1

[Note: ***: significant at 0.001, **: significant at 0.01 and *: significant at 0.05 level].

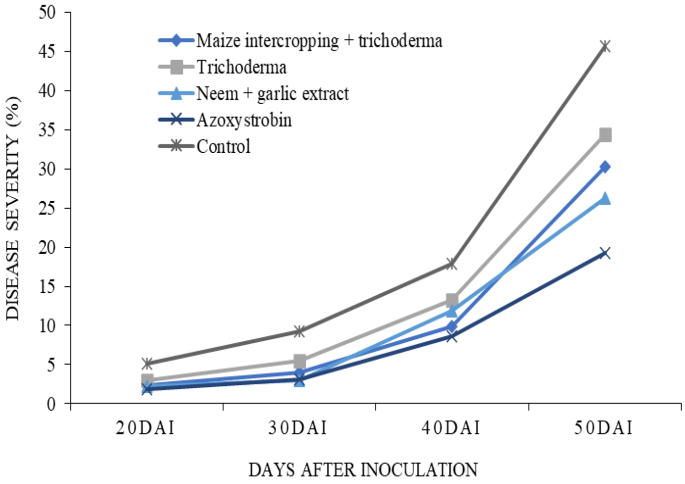

Figure 2. *AUDPC of different rust management practices.*

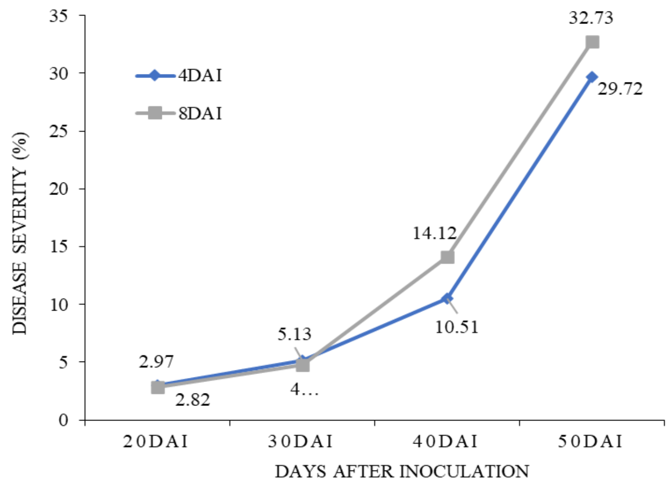

Figure 3. *AUDPC of the fungicide application timings.*

Area Under Disease Progress Curve (AUDPC)

AUDPC for different rust management practices: AUDPC increased at an increasing rate for all the management practices at all the dates of observations, as shown in Figure 2. The control plants showed significantly higher AUDPC at all dates of observations and were followed by Trichoderma. A significantly lower value of AUDPC with the use of Trichoderma viride (845) over control (1536) was also observed by Ismail and Afifi (2019). The effect of maize intercropping with Trichoderma and neem and garlic extracts was at par regarding the development of the disease. The maximum control on disease development was observed with azoxystrobin.

AUDPC for different fungicide application timings: The fungicides, when sprayed at 4 DAI, showed significantly greater control on the disease development at 40 DAI and 50 DAI than those sprayed at 8 DAI as shown in Figure 3.

Conclusion

All the treatments were found to be significantly effective in controlling common bean rust as compared to the untreated control. The foliar treatment of azoxystrobin was found to be the most effective for the management of common bean rust, as minimum disease parameters and maximum vegetative and yield parameters were observed with it. The effects of azoxystrobin, maize intercropping with Trichoderma, and neem and garlic extracts were similar in green pod yield. The spraying of fungicides at 4 DAI was found to be significantly more effective for the management of common bean rust as compared to when it was sprayed at 8 DAI. This might be due to the comparatively longer time interval between inoculation and fungicide application for the uredospore to germinate and penetrate the host. As some of the disease and yield parameters were comparable between azoxystrobin and other treatments, considering residual toxicity and environmental and human health, integrated disease management (IDM) approaches are recommended for the sustainable management of common bean rust.

Data availability statement

The data generated for this study is available at https://doi.org/10.5281/zenodo.7135122.

Declaration of competing interest

All the authors declare no competing interest regarding this manuscript.

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