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Characterization of infection patterns of common bean rust (*Uromyces appendiculatus*) under different management practices

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Abstract

Common bean rust (*Uromyces appendiculatus*) is a widespread disease that causes significant yield loss. A field experiment was laid out in a two-factorial randomized complete block design (RCBD) with three replications to analyze the infection patterns of the rust on common beans. The two factors were the day of spray of fungicides: 4 days after inoculation and 8 days after inoculation, and management practices: intercropping with maize + *Trichoderma viride*, botanical extracts (neem + garlic) (50%), *Trichoderma viride,* and Azoxystrobin (0.1%). The disease severity and necrotic colonies (%) were observed more on the lower leaves due to the first incidence of inoculum, followed by the middle and upper leaves. Azoxystrobin (0.1%) showed maximum control of the disease on all the tiers of bean plants. At 40 days after inoculation, the disease severity with azoxystrobin and neem + garlic was at par on all the tiers of plants. The influence of the alternation on the day of spray of fungicides was observed more on the lower leaves. Fungicides sprayed 4 days after inoculation had a lower severity of infection as compared to those sprayed 8 days after inoculation. Since all the management practices had comparable effects on controlling bean rust, it is recommended to apply an integrated approach 4 days after inoculation. It is also suggested to consider that the severity of rust infection increases from the upper tier to the lower tire for site-specific management of common bean rust.

Keywords – Disease severity – Integrated management – Lower leaves – Necrotic colonies

Introduction

Common bean rust (*Uromyces appendiculatus*) is a serious havoc for commercial bean production. It is one of the most common diseases of *Phaseolus vulgaris* globally, affecting bean-producing areas (Pastor-Corales 2001). It can cause yield losses of 18-100%, depending on the incidence and severity (Souza et al. 2008). *Uromyces appendiculatus* has a diverse host range, including *Phaseolus caracalla*, *P. acutifolius*, *P. coccineus*, *P. maculatus*, *P. nanus, P. ovatus*, *P. polystachyus*, and *P. vulgaris* (Hennen et al. 2005). At the initial stage, small yellowish-white raised spots appear on the upper surface of leaves, which are called pycnia, and later these spots advance to form large reddish spots called uredinia. They have about 1/8th of an inch of diameter and later rupture, releasing numerous urediniospores giving, the infected leaves a rusty appearance (Steadman 1995). The pustules on stems and branches are more elongated than those on leaves.

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The weather, with cool temperatures ranging from 16 to 24 °C and humid conditions with prolonged leaf wetness of 10 to 24 hours, is conducive to rust development (Souza et al. 2008, Schwartz et al. 2011). Light intensity also plays a major role in the germination of urediniospores. Infection is favored by a low light intensity of 2×10^{-5} µE cm^{-2} s^{-1} for about 18 hours (Augustin et al. 1972). Germination of uredospores occurs in 6-8 hours, depending on the temperature and moisture (Souza et al. 2008).

For proper management of this disease, it is necessary to know its infection patterns. This particular knowledge may help to recommend different doses of fungicides for different tiers of plants. Moreover, we can optimize the fungicidal dose based on the severity of infection in a particular part of a plant. In other words, knowledge of infection patterns helps in the site-specific allocation of the required amount of fungicides. The proper understanding of the infection pattern of common bean rust may also lead to the development of a suitable model that can be programmed in an automated machine at the time of application of fungicides. Moreover, for the sustainable management of this disease, an integrated management approach is necessary (Surviliene & Dambrauskiene 2006, Harveson et al. 2013). It minimizes the problems of the development of resistance to pathogens and causes less harm to the environment and human health. Thus, this research focuses on the infection patterns, including disease severity and necrotic rust colonies (%) of *U. appendiculatus* on different tiers of plants under integrated rust management.

Materials & Methods

Experimental site and weather conditions

The experiment was conducted in a field at Jugedi, Chitwan, from March to May 2022, at an elevation of 291 m above sea level. The soil of the experimental field has a medium nitrogen content and a low amount of phosphorus and potassium, with a pH value of 6.5. The details of the weather during the experiment are given in Fig. 1.

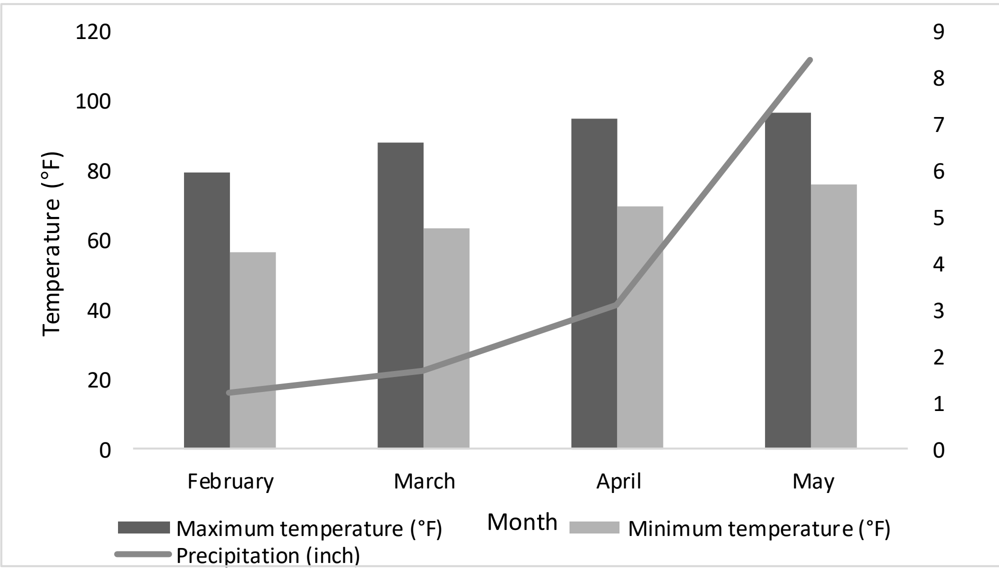

Fig. 1 – Weather parameters during the experiment at Bharatpur, Chitwan, 2022. (Weather Spark 2022).

Experimental design

The experiment was laid out in a two-factorial randomized complete block design (RCBD) with three replications of each treatment. Blocks were designed based on the shadiness of the trees from left to right. The size of each plot was 2.5 m × 1.5 m (Bhandari et al. 2023). The total number of plots was 30, and 10 was on each block. The block-to-block and row-to-row distances were maintained at 1m each.

Treatments details

The different management practices and the day of spray of fungicides were selected as two factors. The levels of the day of spray of fungicides (D) and management practices (M) are presented in Table 1.

Table 1 Description of the treatments used in the experiment (Bhandari et al. 2023).

Treatment symbol	Description
T1 (D1M1)	4DAI (Days After Inoculation), Maize and bean intercropping (3:4 ratio) + *Trichoderma viride* (5 mL/L water)
T2 (D1M2)	4DAI, *Trichoderma viride* (5 mL/L water)
T3 (D1M3)	4DAI, garlic + neem extract (50%) (1:1 ratio), (6 ml/L water each)
T4 (D1M4)	4DAI, Azoxystrobin (0.1%)
T5 (D1M0)	4DAI, no fungicide (control)
T6 (D2M1)	8DAI, Maize and bean intercropping (3:4 ratio) + *Trichoderma viride* (5 mL/L water)
T7 (D2M2)	8DAI, *Trichoderma viride* (5 mL/L water)
T8 (D2M3)	8DAI, garlic + neem extract (50%) (1:1 ratio), (6 mL/L water each)
T9 (D2M4)	8DAI, Azoxystrobin (0.1%)
T10 (D2M0)	8DAI, no fungicide (control)

Inoculum preparation and inoculation

The inoculum was procured from the rust-infected common bean plant in the farmer's field. It was observed under a microscope, and identification was done as described by Cummins (1978). The uredospore suspension was prepared in the laboratory and standardized with the help of a hemocytometer to reach the required concentration of 10^5/mL water (Sackston 1960, Bhandari et al. 2023). The suspension was inoculated by using an electric sprayer until runoff at 30 DAS (Days After Sowing) (Mersha & Hau 2008). Common beans of Italy-38 variety, produced by Guangdong Helinongseeds Company Limited in China and imported and distributed by Gorkha Seed and Agro Traders in Nepal, were used for the study.

Preparation of botanical extracts, fertilizer application, and irrigation

Neem and garlic extracts were prepared by following the methods described by Al-Charchafchi et al. (2007). Urea, DAP (di-ammonium phosphate), and MOP (muriate of potash) were applied at a ratio of 80:120:60 kg/ha (Bhandari et al. 2023). The first irrigation was done immediately after germination at 20 DAS as the field was dry. After that, two irrigations were applied at 35 DAS and 60 DAS.

Data collection and parameters recorded

The data were collected from the five randomly selected plants in the individual plots. The data were recorded independently for three tiers of the plant: lower leaves, middle leaves, and upper leaves at 20, 30, 40, and 50 days after inoculation (Bhandari et al. 2023). The diagrammatic scale developed by Godoy et al. (1997) was used for the disease scoring.

Disease severity and necrotic colonies (%) were recorded from each tire of a plant to determine the infection pattern of the rust on its host. The formulae for disease severity and necrotic colonies (%) are given below.

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

$$\text{Necrotic colonies (\%)} = \frac{\text{Number of rust colonies with necrosis}}{\text{Total number of rust colony}} \times 100$$

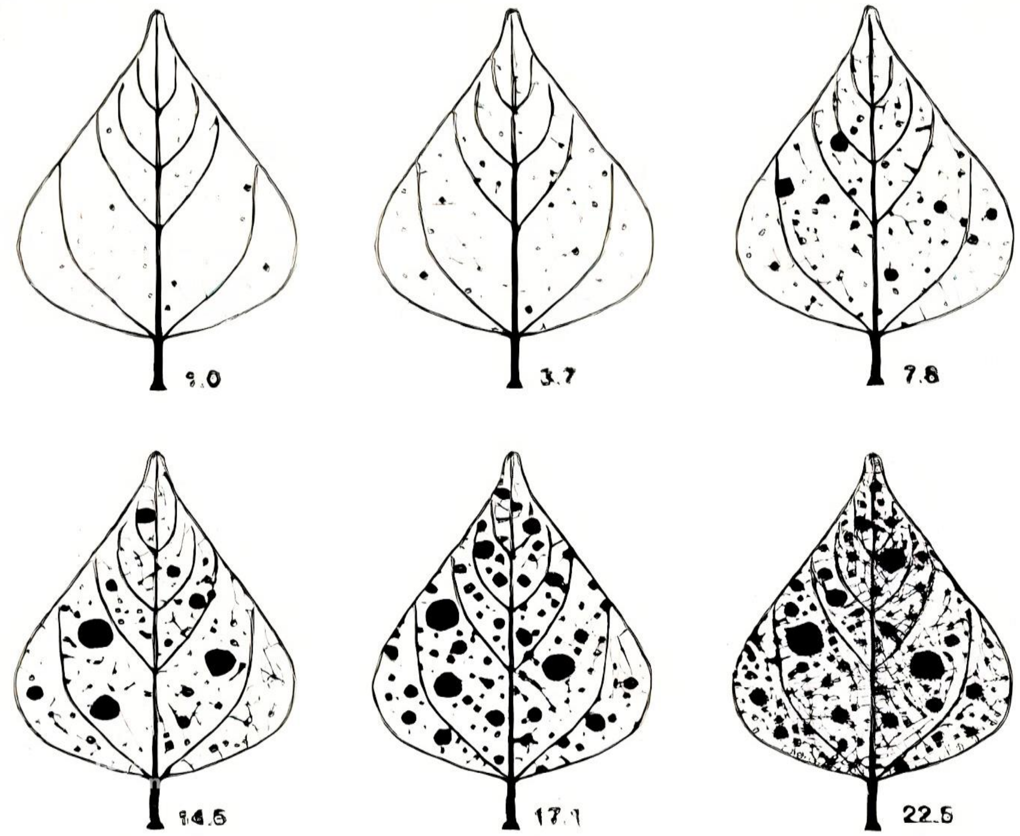

Fig. 2 – Diagrammatic scale of severity of rust (*Uromyces appendiculatus*) (Godoy et al. 1997).

Data analysis

The recorded data were analyzed in R-studio (version 4.1.2). The significant difference in the mean value for each treatment was computed by using Ducan's Multiple Range Test (DMRT) at a 5% level of significance.

Results

Disease severity on lower leaves

Different management practices had a significant impact on the disease severity of lower leaves at all the dates of observations, while the days of spray of fungicides had a significant impact at 40 DAI (Fig. 3). At 20 DAI, maximum disease severity was observed in the control plots (9.0%). All the other treatments were statistically at par. At 30 DAI, maximum disease severity on lower leaves was found in the control (19.04%), which was statistically at par with Trichoderma (13.48%). The least disease severity was observed with neem + garlic extract (5.17%), which was at par with azoxystrobin and maize intercropping + Trichoderma. At 40 DAI, the control plot showed maximum disease severity (35.69%), which was at par with Trichoderma-treated plots (26.31%). All the other treatments were at par and had significantly less disease severity than the control. At 50 DAI, the maximum disease severity was observed in the control (78.34%), followed by Trichoderma (64.76%). The effects of neem + garlic extract and maize intercropping + Trichoderma were at par but significantly less severe than the control and Trichoderma-sprayed plots. The lowest disease severity on lower leaves was found with the treatments of azoxystrobin (37.06%). The disease severity was found to be less at 40 DAI when the fungicides were sprayed at 4 DAI (21.35%) than those sprayed at 8 DAI (29.09%) (Table 4).

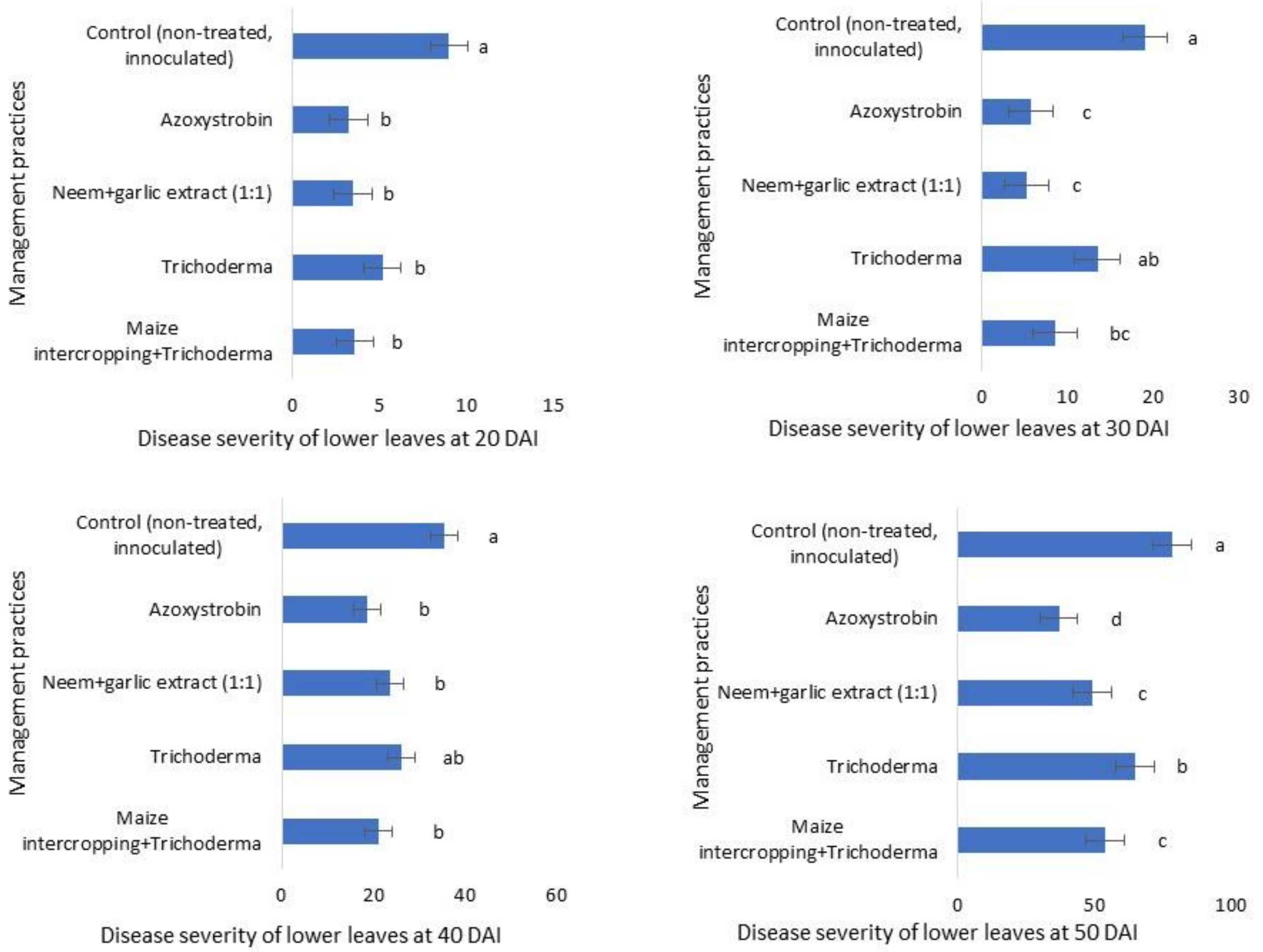

Fig. 3 – Disease severity of the lower leaves at 20, 30, 40, and 50 DAI.

Interaction effect of disease severity of rust on lower leaves of common bean at 50 DAI

The maximum disease severity on lower leaves was observed in the control (83.33%). The effect of Trichoderma at both 4 DAI and 8 DAI and maize intercropping + Trichoderma at 8 DAI were at par. Azoxystrobin and neem + garlic extract at 8 DAI and maize intercropping + Trichoderma and neem + garlic extract were at par related to disease severity. The least disease severity was observed with azoxystrobin sprayed at 4 DAI (31.09%) (Table 2).

Table 2 Interaction effect of management practices and day of spray of fungicides on disease severity of rust on lower leaves of common bean at 50 DAI.

Management practices	**Day of spray**	
	4DAI	**8DAI**
Maize intercropping+Trichoderma	48.68^{de}	59.15^{cd}
Trichoderma	65.45^{bc}	64.07^{bc}
Neem+garlic extract (1:1)	46.07^{e}	52.26^{de}
Azoxystrobin	31.09^{f}	43.03^{e}
Control	83.33^{a}	73.35^{ab}
SEM (±)	3.42	
F-test	*	
LSD	10.15	
C.V.%	10.44	
Grand mean	56.65	

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 0.05 level

Disease severity on middle leaves

The different management practices had a significant impact on the disease severity of middle leaves at 20 DAI, 30 DAI, and 50 DAI (Fig. 4), while the day of spray of fungicides had a significant impact on it at 30 DAI. At 20 DAI, maximum disease severity on middle leaves was observed in the control plots (5.38%). The rest of the treatments had a statistically similar impact. At 30 DAI, a similar result was observed. The control plots showed the highest severity (6.35%). Disease severity on middle leaves was found to be significantly higher at 30 DAI when fungicides were sprayed at 4 DAI (3.77%) than at 8 DAI (2.60%) (Table 4). At 50 DAI, the control plot showed maximum disease severity (48.77%). It was followed by Trichoderma (30.61%), which was statistically at par with maize intercropping + Trichoderma and neem + garlic extract. The least disease severity was observed with the treatment of azoxystrobin (17.43%), which was at par with maize intercropping + Trichoderma and neem + garlic extract.

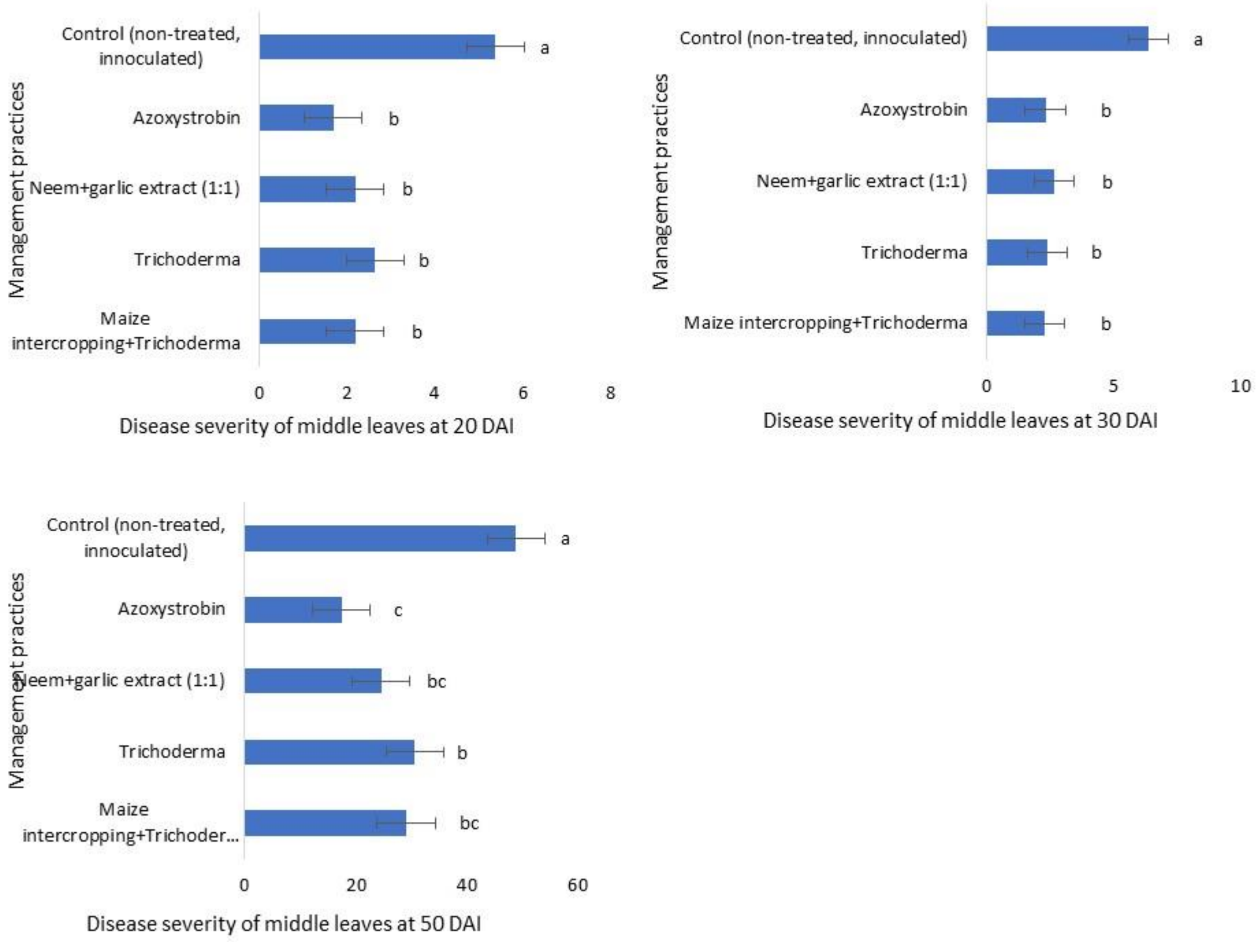

Fig. 4 – Disease severity of the middle leaves at 20, 30, and 50 DAI.

Interaction effect of different management practices and day of the spray of fungicides on disease severity of rust on middle leaves of common beans at 30 DAI

The interaction effect of different management practices and the day of spray of fungicides was observed on the disease severity of middle leaves at 30 DAI (Table 3). The maximum disease severity was seen in the control plots (9.40%). The effect of all the other treatments was statistically at par on both days of spray. The disease severity in the control plots where water was sprayed at 4 DAI was significantly higher than the control plots sprayed at 8 DAI; this might be due to the increased moisture on leaves providing a conducive environment at the time of host penetration and pathogen development.

Table 3 Interaction effect of management practices and day of spray of fungicides on disease severity of rust on middle leaves of common bean at 30 DAI.

Management practices	**Day of spray**	
	4 DAI	**8 DAI**
Maize intercropping+Trichoderma	2.46[b]	2.06[b]
Trichoderma	2.39[b]	2.39[b]
Neem+garlic extract (1:1)	1.97[b]	3.30[b]
Azoxystrobin	2.64[b]	1.97[b]
Control	9.40[a]	3.30[b]
SEM (±)	0.83	
F-test	**	
LSD	2.45	
C.V.%	44.80	
Grand mean	3.19	

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 the mean, **: significant at 0.01

Disease severity on upper leaves

The different management practices had a significant impact on the disease severity of the upper leaves of common bean only at 40 DAI (Fig. 5). The maximum disease severity on the upper leaves at 40 DAI was observed in the control (4.04%). All the other treatments were statistically at par. There is no significant impact of the day of spray of fungicides on the disease severity of upper leaves (Table 4).

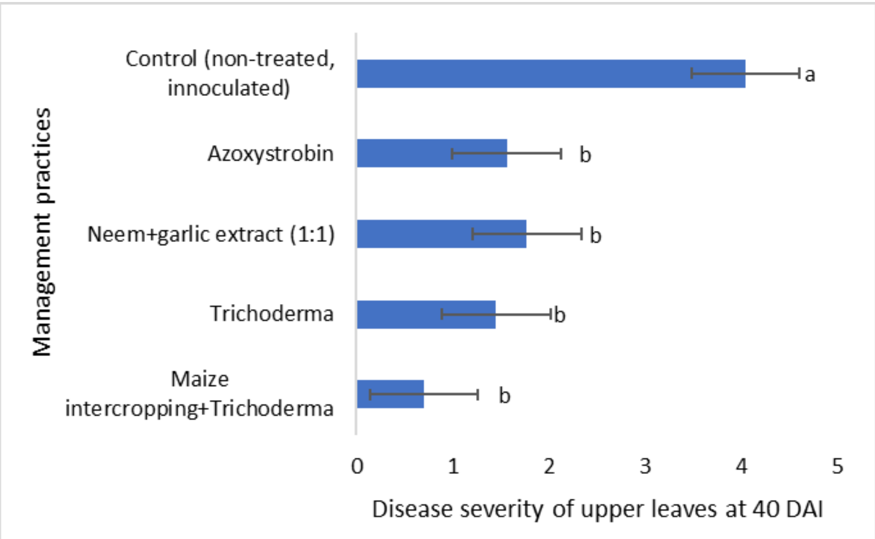

Fig. 5 – Disease severity of the upper leaves at 40 DAI.

Necrotic colonies (%) on the lower leaves

The percentage of rust colonies with necrosis on lower leaves was significantly influenced by different management practices at all dates of observations (Fig. 6), while it was influenced by the day of spray of fungicides at 40 DAI and 50 DAI. At 20 DAI, the percentage of colonies with necrosis was maximum for the control (16.74%), which was at par with Trichoderma (Fig. 6). At 30 DAI, the control plant showed the maximum percentage of colonies with necrosis (24%). The lowest percentage of colonies with necrosis was observed with azoxystrobin (5.63%), which was at par with maize intercropping + Trichoderma and neem + garlic extract. At 40 DAI, it was found significantly higher in the control (52.83%), followed by Trichoderma (37.26%). The lowest percentage of colonies with necrosis was observed in azoxystrobin-treated plants (10.83%), which was at par with maize intercropping + Trichoderma and neem + garlic extract. At 50 DAI, again, the control plots showed a maximum percentage of colonies with necrosis (89.08%), followed by Trichoderma (56.66%). The effect of maize intercropping + Trichoderma and neem + garlic extract was similar to rust colonies with necrosis but significantly more effective than Trichoderma. Azoxystrobin-sprayed plants showed the fewest colonies of necrosis (21.50%). Colonies with necrosis were found more often when the fungicides were applied at 8 DAI on 40 DAI and 50 DAI (Table 5).

Table 4 Effects of day of spray of fungicides on the disease severity of lower, middle, and upper leaves of common bean.

		Disease severity of lower leaves			
	Treatment	20 DAI	30 DAI	40 DAI	50 DAI
Day of spray					
	4 DAI	5.06	10.21	21.35[b]	54.92
	8 DAI	4.71	10.57	29.09[a]	58.37
	SEM (±)	2.29	1.56	1.92	1.53
	F-test	NS	NS	*	NS
	LSD	1.60	4.63	5.71	4.54
		Disease severity of middle leaf			
	Treatment	20 DAI	30 DAI	40 DAI	50 DAI
Day of spray					
	4 DAI	3.17	3.77[a]	8.43	27.67
	8 DAI	2.45	2.60[b]	11.21	32.52
	SEM (±)	0.49	0.37	1.42	2.55
	F-test	NS	*	NS	NS
	LSD	1.44	1.09	4.21	7.58
		Disease severity of upper leaves			
	Treatment	20 DAI	30 DAI	40 DAI	50 DAI
Day of spray					
	4 DAI	0.69	1.40	1.76	6.57
	8 DAI	1.31	1.07	2.05	7.29
	SEM (±)	0.29	0.36	0.46	0.93
	F-test	NS	NS	NS	NS
	LSD	0.88	1.06	1.36	2.75

Table 5 Effects of the day of spray of fungicides on the necrotic colonies (%) of lower, middle, and upper leaves of common bean.

		Necrotic colonies (%) of lower leaves			
	Treatment	20 DAI	30 DAI	40 DAI	50 DAI
Day of spray					
	4 DAI	7.64	12.33	23.37[b]	42.4[b]
	8 DAI	9.69	14.83	32.80[a]	52.1[a]
	SEM (±)	1.41	1.34	2.33	1.35
	F-test	NS	NS	*	***
	LSD	4.17	3.97	6.91	4.01
		Necrotic colonies (%) of middle leaves			
	Treatment	20 DAI	30 DAI	40 DAI	50 DAI
Day of spray					
	4 DAI	3.76	5.22[b]	16.14	23.66[b]
	8 DAI	3.72	6.75[a]	21.13	31.30[a]
	SEM (±)	0.59	0.49	3.04	1.98
	F-test	NS	*	NS	*

Table 5 Continued.

	LSD	1.73	1.44	9.05	5.87
		Necrotic colonies (%) of upper leaves			
	Treatment	20 DAI	30 DAI	40 DAI	50 DAI
Day of spray					
	4 DAI	0.67	1.34	6.13	9.73[b]
	8 DAI	0.37	2.40	8.20	12.63[a]
	SEM (±)	0.44	0.38	0.77	0.56
	F-test	NS	NS	NS	**
	LSD	1.31	1.12	2.31	1.66

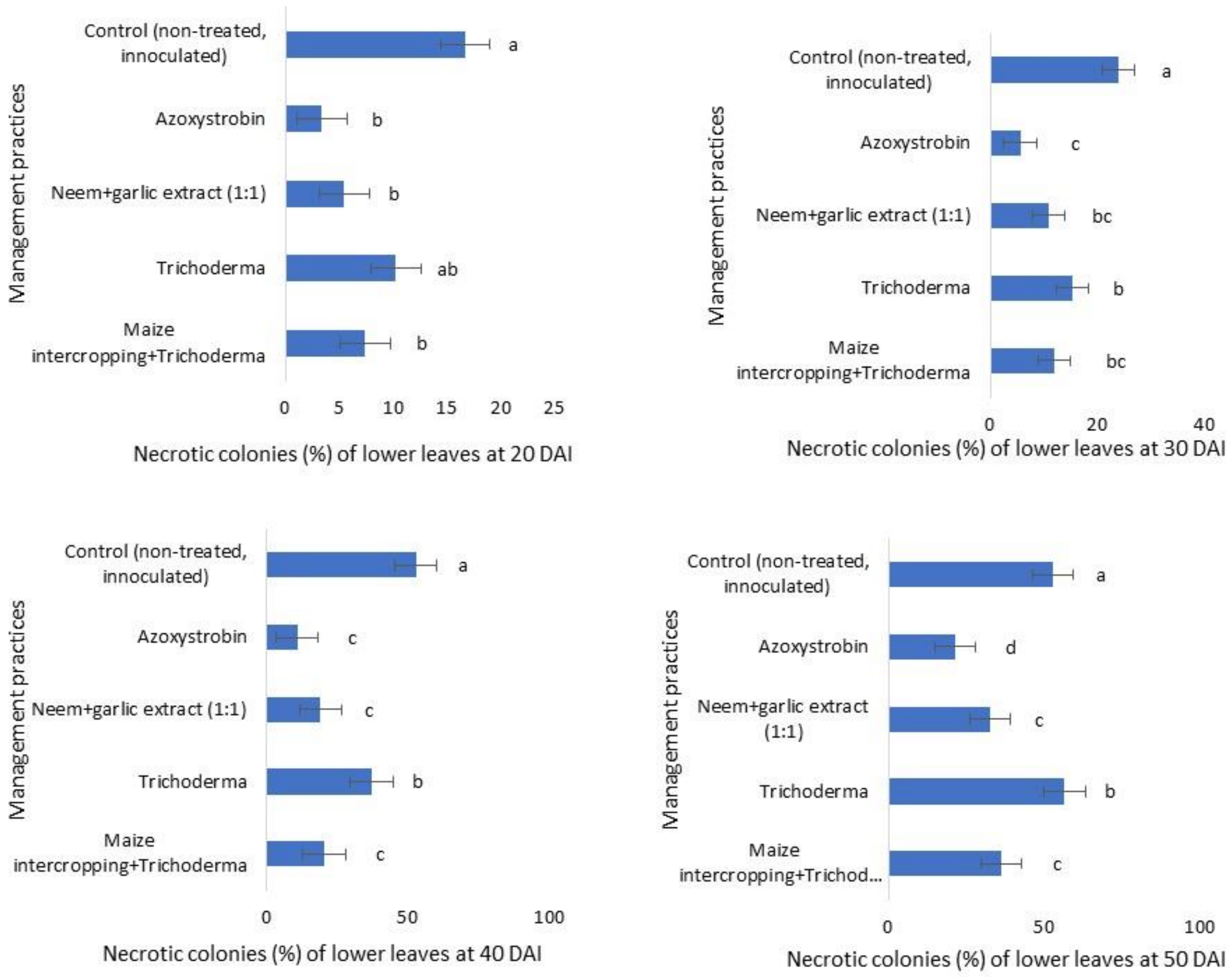

Fig. 6 – Effects of different management practices on the necrotic rust colonies (%) on lower leaves at 20, 30, 40, and 50 DAI.

Necrotic colonies (%) on the middle leaves

The management practices had a significant impact on the percentage of rust colonies with necrosis on middle leaves at all dates of observations (Fig. 7), while the day of spray of fungicides had a significant impact at 30 DAI and 50 DAI on this parameter. At 20 DAI, the Trichoderma-treated plots showed the highest colonies with necrosis (5.94%), which is at par with the control, maize intercropping + Trichoderma, and neem + garlic extract. The last colonies with necrosis was observed with azoxystrobin (0.66%), which was at par with maize intercropping + Trichoderma and neem + garlic extract. At 30 DAI, the control plot showed the maximum colonies with necrosis (9.83%). It was followed by Trichoderma (7.50%), which was at par with maize intercropping +

Trichoderma. The last colonies with necrosis was found with azoxystrobin (2%) and was at par with neem + garlic extract. At 40 DAI, the control plot showed the highest colonies with necrosis, followed by Trichoderma (26.03%). The least percentage of colonies with necrosis was observed in azoxystrobin-treated plots (4.5%), which had a similar effect as maize intercropping + Trichoderma and neem + garlic extract. At 50 DAI, a similar result was observed as that at 40 DAI. The rust colonies with necrosis was significantly less when fungicides were sprayed at 4 DAI on 30 DAI and 50 DAI (Table 5). For all the management practices, the rust colonies with necrosis on the middle leaves increased with the development of the disease.

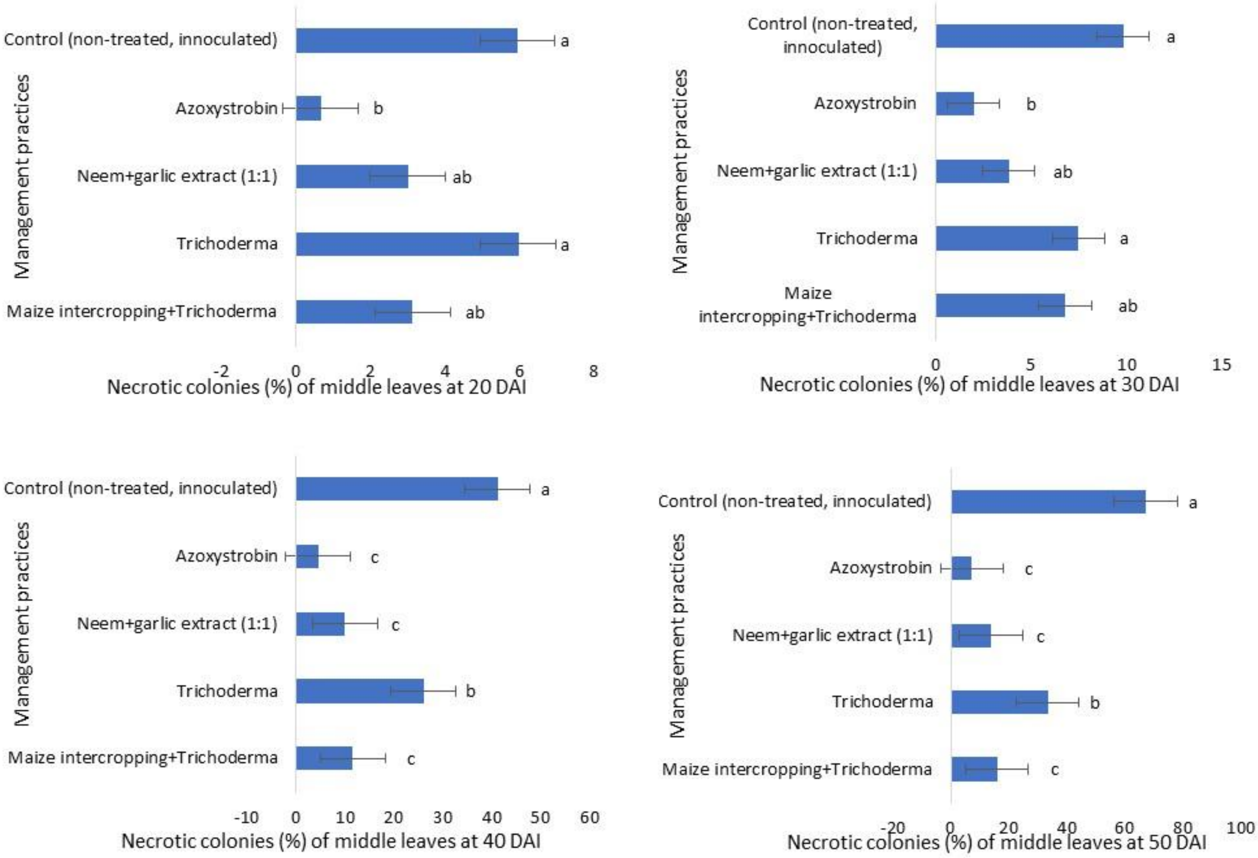

Fig. 7 – Effects of different management practices on the necrotic rust colonies (%) on middle leaves at 20, 30, 40, and 50 DAI.

Necrotic colonies (%) on the upper leaves

The percentage of rust colonies with necrosis on upper leaves was significantly influenced by different management practices at 30 DAI, 40 DAI, and 50 DAI (Fig. 8), while it was influenced by the day of spray of fungicides at 50 DAI. At 30 DAI, the maximum colonies with necrosis were observed in the control (3.83%), which was at par with Trichoderma. The least colonies with necrosis were for azoxystrobin (0.16%), which was at par with maize intercropping + Trichoderma and neem + garlic extract. The percentage of colonies with necrosis observed at 40 DAI was found to be the maximum for the control (16.67%), followed by Trichoderma (9.16%). The rest of the management practices had a similar impact on this parameter at 40 DAI. At 50 DAI, the control plant showed the highest colonies with necrosis (25.66%) and was followed by Trichoderma (12.33%). Maize intercropping with Trichoderma and neem + garlic extract were at par but significantly more effective in reducing necrosis than Trichoderma. The least colonies with necrosis were observed in azoxystrobin-treated plants (3.66%). Modesto et al. (2005) reported over 90% efficiency of azoxystrobin (50 g/ha) + nimbex (0.25%) in controlling bean rust. Fungicides sprayed at 4 DAI had significantly fewer colonies with necrosis at 50 DAI as compared to 8 DAI (Table 5).

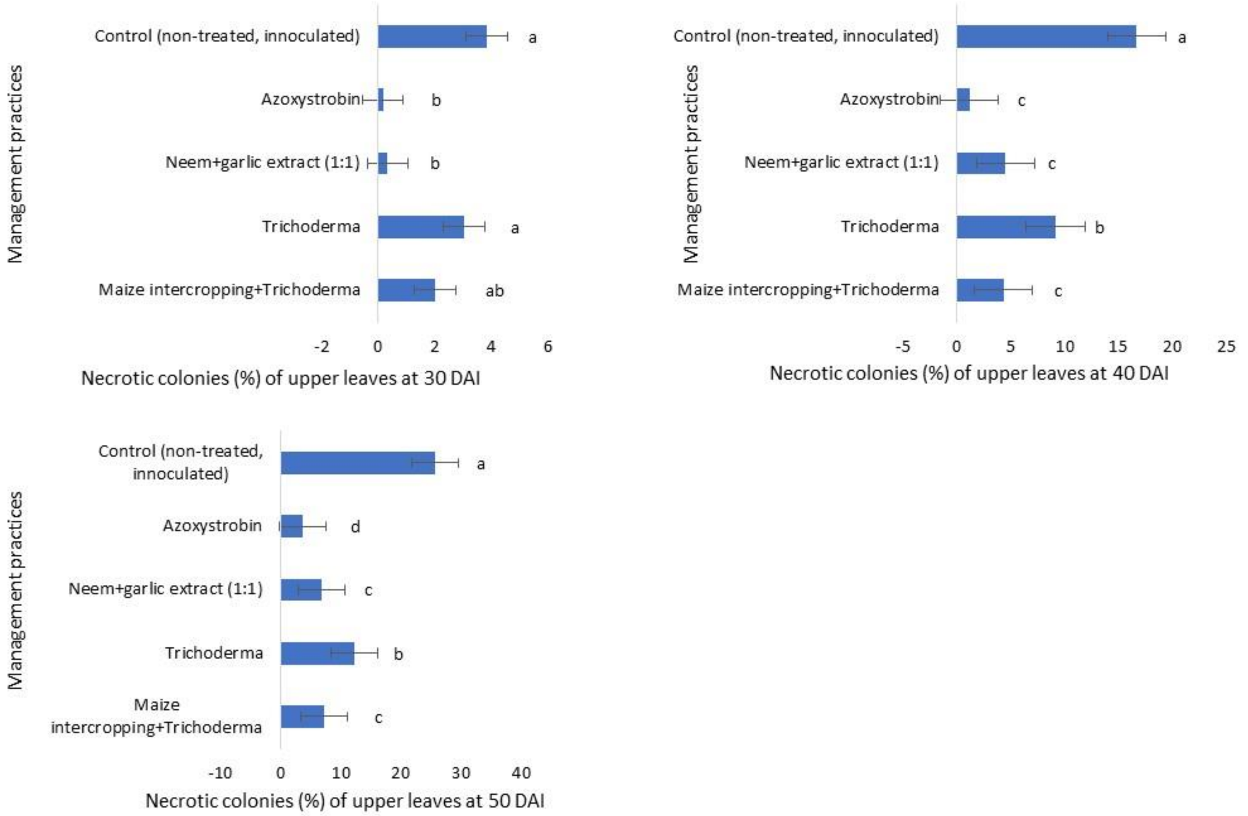

Fig. 8 – Effects of different management practices on the necrotic rust colonies (%) on upper leaves at 30, 40, and 50 DAI.

Discussion

The disease severity on the lower leaves was significantly influenced by different management practices at all the dates of observation from 20 DAI. Habtu & Zadoks (1994) also reported a significant effect of treatments on disease severity, pustule density, and pustule size at the pre-flowering stage for lower leaves. The severity of the rust infection was observed more on the lower leaves, followed by the middle and upper leaves. This might be because the rust affects the first trifoliate leaves, which in turn become lower leaves. The dispersal of uredospore occurs among lower leaves at first (Rouse et al. 1980, Kolbe 1982) and then it moves toward upper leaves. Though the rate of defoliation is higher on lower leaves (Zadoks & Schein 1979), the average rust severity is always higher in the lower or middle canopy as compared to the upper canopy, as shown by this study. The rate of increase in the severity of infection was higher on the lower leaves, followed by the middle and upper leaves. The percentage of rust colonies with necrosis on lower leaves was significantly influenced by different management practices after 20 DAI. Habtu & Zadoks (1994) also observed a significant difference in pustule density on lower leaves after the third trifoliate leaf onward. At 20 DAI, the necrotic colonies (%) were minimal for Azoxystrobin on the lower leaves, which was at par with maize intercropping + Trichoderma. The maize intercropping acts as a barrier and limits the spread of inoculum (Chhetry & Mangang 2012).

The minimum disease severity on middle leaves at 50 DAI was observed with Azoxystrobin, which is similar to neem + garlic extracts. Fulano (2016) also reported a moderate reduction in rust severity by 27% during November-January and by 40% during March-May with the treatment of garlic extract. Monda et al. (2009) also reported the effectiveness of neem extract to control bean rust as compared to the control. The necrotic colonies (%) were found more on the lower and middle leaves as compared to the upper leaves. According to Habtu & Zadoks (1994), pustule density was significantly higher for middle and lower leaves.

A significant influence of different management practices was observed on the upper leaves at 40 DAI. A significant difference in the upper canopy on rust severity was observed at 20 days after pod setting (Habtu & Zadoks 1994), which is consistent with this study. The least disease severity was observed with Azoxystrobin at 40 DAI on upper leaves, which was at par with *Trichoderma viride*. Modesto et al. (2005) reported over 90% efficiency of azoxystrobin (50 g/ha) + nimbex (0.25%) in controlling bean rust. *Trichoderma viride* reduced rust severity by 73% each during November-January and March-May in a study conducted by Fulano (2016). The percentage of rust colonies with necrosis on upper leaves was significantly influenced by different management practices after 30 DAI, while it was influenced by the day of spray of fungicides at 50 DAI. A significant difference in the upper canopy's pustule density was observed 10 days after the pod setting (Habtu & Zadoks 1994).

The day of spray of fungicides had more significant impacts on the lower and middle leaves as compared to the upper leaves. The upper leaves have generally less severity of infection, so very little alteration in the infection was observed upon earlier application of fungicides. The disease severity and necrotic colonies (%) were found to be lower when the fungicides were sprayed at 4 DAI than when sprayed at 8 DAI. This increase in the severity of infection with the late application of fungicides after inoculation might be due to the allocation of more time for the pathogen to penetrate and develop on the host.

Conclusion

The pattern of infection varies among the different tiers of bean plants. Disease severity under different management practices was observed at its maximum for the lower leaves, followed by the middle leaves, and then the upper leaves. The case is also the same for the percentage of necrotic colonies. This increase in the severity of infection from upper to lower might be due to the rust incidence on the lower leaves at first. The rate of increase in the severity of infection was also greatest for the lower leaves and the least for the upper leaves. The different management practices had significant impacts on the severity of infection in all the tiers of plants. The minimum disease severity and necrotic colonies were observed with Azoxystrobin (0.1%). Other management practices such as maize and bean intercropping (3:4 ratio) + *Trichoderma viride* (5 mL/L water), *Trichoderma viride* (5 mL/L water), garlic + neem extract (50%) (1:1 ratio), (6 mL/L water each) had significantly reduced rust severity as compared to the untreated control. The influence of the day of spray of fungicides was observed more on the lower and middle leaves as compared to the upper leaves. The fungicide sprayed at 4 DAI had less severity of infection than that sprayed at 8 DAI, which might be due to the shorter time for the inoculum to penetrate the host. This study recommends the site-specific spray of fungicides at 4 DAI, with more amounts on the lower tier for their optimization and effectiveness in controlling the disease. Moreover, as all the management practices were significantly effective against the disease, it is suggested to apply an integrated disease management approach for the sustainable management of common bean rust.

Declaration of competing interest

All the authors have declared that there is no conflict of interest.

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