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Management of Pea Wilt Incitant by *Fusarium oxysporum* f. sp. *pisi* (Linford) using AM Fungi *Gigaspora margarita* Inoculation at various Phosphorus Amendments in Pea (*Pisum sativum* L.)

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***Abstract*:** The pea (*Pisum sativum* L.) is an important vegetable and pulse crop in subtropical and temperate areas. The present study investigated the potential of *Gigaspora margarita*, an arbuscular mycorrhizal fungus (AMF), as a biocontrol agent against *Fusarium oxysporum* f. sp. *pisi* (FOP), the pathogen causing pea wilt. Experiments were conducted under pot house conditions at two locations in Punjab (Ludhiana and Abohar) during the *rabi* season of 2022-2023 to assess the impact of AMF on mycorrhization and disease suppression when co-inoculated with the pathogen.The pre-treating plants with AMF significantly reduced wilt disease incidence compared to inoculating with FOP at sowing followed by AMF application. Early AMF inoculation promoted mycorrhizal colonization, resulting in up to an 86.67% reduction in disease intensity at 40 mg phosphorus per kg of soil. This suggests that soil treatment with AMF before planting is an effective bioprotective strategy against pea wilt.

***Keywords*:** Arbuscular Mycorrhizal Fungi, *Gigaspora margarita*, *Fusarium oxysporum* f. sp. *pisi*, Pea wilt

Pea (*Pisum sativum* L.) ranks as the fourth most significant cultivated legume, following common bean, cowpea, and chickpea globally (Faostat 2019). In India, after chickpeas and lentils, pea rank as the third most popular *rabi* pulse crop. Pea cultivation covers 589 thousand hectares, yielding a production of 6130 metric tons (Indiastat 2021-22). In Punjab, during 2021-22, pea was cultivated on 44.1 thousand hectares, producing approximately 469.4 thousand tons, with an average yield of 42.90 quintals per acre (Anonymous 2022).

Pea production faces significant challenges due to various diseases affecting its productivity. In Northern India, wilt is emerging as a challenge for pea cultivation, the primary cause of wilt is fungus *Fusarium oxysporum* f. sp. *pisi* (linford) Snyder and Hansen. This soil-borne fungus can persist in the soil as a chlamydospores for more than ten years (Deng et al*.,* 2022). In the Hoshiarpur district of Punjab, crop losses due to a disease complex caused by *Fusarium solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* were in the range between 13.9 and 95 percent (Kripalini et al., 2019).

Effective management of wilt is essential to mitigate substantial losses in pea crops. However, growers face various challenges in controlling this disease, as conventional chemical treatments provide only limited control, and resistant varieties are unavailable against this disease in Punjab. Furthermore, chemical pesticides are becoming progressively costly and less efficient due to the co-evolution and emergence of disease resistance and their unintended consequences on non-target organisms. Bioprotection, a well-documented and increasingly significant approach, is frequently used to supplement or substitute chemical methods. Arbuscular mycorrhizal fungi (AMF) have great potential as a biocontrol agent. The study examines the impact of *Fusarium oxysporum* f. sp. *pisi* on mycorrhization (root colonization and AMF spore population/100-gram soil) and effects of AMF on inhibiting disease caused by *Fusarium oxysporum* f. sp. *pisi*.

MATERIAL AND METHODS

The experiments were carried out during the 2022-23 *Rabi* season at two locations, Ludhiana and Abohar, under controlled pot house conditions using sterilized soil. The Arbuscular Mycorrhizal Fungus *Gigaspora margarita* was procured as pure culture from the Centre for Natural Biological Resources and Community Development (CNBRCD), Bengaluru, Karnataka. AMF colonization was assessed by staining the roots following the procedure outlined by Phillips and Hayman (1970). Arbuscular mycorrhizal (AM) infection was quantified following the procedure recommended by Biermann and Lindermann (1981). AMF spores were isolated using the wet sieving and decanting method (Gerdemann and Nicolson 1963). The spore population was then quantified using a counting dish in a 25 ml spore suspension. *Gigaspora margarita* inoculum

was multiplied on the roots of pea plants in sterilized soil within the pot house. A thin layer of AMF inoculum weighing 10grams containing AMF spores, AMF hyphae and root bits were placed in 4 Kg of sterilized soil 4 cm below the upper surface of the soil in an earthen pot (Singh et al., 2019). "MATAR AGETA 7" pea variety was used in the present study. Pathogen *Fusarium oxysporum* f. sp. *pisi* (ITCC Number = 4814) was obtained from the Indian Type Culture Collection, IARI. FOP was maintained by periodic transfer on PDA slants and the culture was stored at 4°C for further use. The experiments aimed to evaluate the impact of arbuscular mycorrhizal fungi on the disease inhibition of pea wilt. Four treatments were applied: 1. Arbuscular mycorrhizal fungus (AMF) only, 2. AMF/Pathogen (AMF inoculation at sowing and pathogen inoculation after 5 days of sowing), 3. Pathogen/AMF (Pathogen inoculation at sowing and AMF inoculation after 5 days of sowing) and 4. Pathogen (*Fusarium oxysporum* f. sp. *pisi*) alone. The experiment also included three levels of phosphorus in the soil at 0, 40 and 80 mg phosphorus/kg soil (P_0, $P_{40,}$ P_{80}). All treatments were replicated three times in both locations. Colonization and spore population observations were recorded by uprooting the plants 20, 40, 60 and 80 days after sowing. For calculating the percentage of disease inhibition by *Gigaspora margarita*, 10 plants were maintained in pots for each treatment.

Stataistical analysis: All the data collected were subjected to statistical analysis using analysis of variance with a complete randomized design in the CPCS1 program. The necessary, data were transformed using the arcsine transformation.

RESULTS AND DISCUSSION

Effect of pathogen and phosphorus on mycorrhization

The study evaluated root colonization and spore populations of the arbuscular mycorrhizal fungus (*Gigaspora margarita*) under both the presence and absence of the pea wilt pathogen, *Fusarium oxysporum* f. sp. *pisi*.

Mycorrhizal effect:AMF *Gigaspora margarita* root colonization increased over time. When AMF alone was inoculated, colonization increased from 30.48 per cent at 20 DAS to 74.72 per cent at 80 DAS in Ludhiana (Table 1), and from 25.71 per cent at 20 DAS to 71.45 per cent at 80 DAS in Abohar (Table 2). However, the presence of the pathogen (FOP*)* negatively impacted AMF colonization. When AMF was applied at sowing and the pathogen was added 5 days later (AMF/Pathogen), colonization increased from 25.68 per cent at 20 DAS to 67.67 per cent at 80 DAS in Ludhiana, and from 20.88 per cent at 20 DAS to 61.44 per cent at 80 DAS in Abohar. This was higher than the colonization observed when the pathogen was introduced at sowing and AMF was applied 5 days later (Pathogen/AMF), which increased from 21.05 per cent at 20 DAS to 61.56 per cent at 80 DAS in Ludhiana, and 17.04 per cent at 20 DAS to 55.30 per cent at 80 DAS in Abohar. No mycorrhizal colonization was detected in the treatment with only the pathogen at either location.

Similar trends were observed for the spore population of AMF *Gigaspora margarita* in pea plant rhizospheric soil. In Ludhiana, the spore population in 100 grams of soil increased from 333.33 spores at 20 DAS to 778.67 spores at 80 DAS (Table 3), and in Abohar, it increased from 258.33 spores at 20 DAS to 660.56 spores at 80 DAS (Table 4) when AMF alone was inoculated. The presence of the pea wilt pathogen FOP, influenced spore formation by *Gigaspora margarita*. In AMF/Pathogen treatment, 100 grams of rhizosphere soil showed an average of 252.78 spores at 20 DAS, increasing to 650.67 spores in the soil at 80 DAS in Ludhiana, and in Abohar, the spore population was 186.11 spores at 20 DAS, increasing to 544.44 spores at 80 DAS. In the Pathogen/AMF treatment, the average spore counts of 100 grams rhizosphere soil were 211.11 spores at 20 DAS to 560.67 spores at 80 DAS in Ludhiana, and 136.11 spores at 20 DAS to 472.22 spores at 80 DAS in Abohar. No mycorrhizal spores were found at any stage of crop growth in the treatment with only the pathogen at both locations.

Singh et al. (2019) they also reported that root colonization by *Glomus macrocarpon* increased from 31.7 percent at 15 DAS to 72.2 percent at 60 DAS in spring season (2017) and 28.3 percent at 15 DAS to 69.3 DAS in spring season (2018) of mungbean crop. Similarly, Kaur (2021) also observed increased root colonization in chickpea with crop maturity from 42.7 percent at 30 DAS to 79.3 percent at 120 DAS in chickpea crop. Sohrabi et al (2015), noted a decline in *Glomus mosseae* colonization in chickpea roots from 78.75 per cent to 57.50 per cent in the presence of *Fusarium solani* f.sp. *pisi*.

Phosphorus effect: Phosphorus application significantly enhanced AMF colonization and spore population across all treatments in both Ludhiana and Abohar. In Ludhiana, AMF colonization for the P_{40} increased from 23.20 per cent at 20 DAS to 55.50 per cent at 80 DAS, while in P_0 treatments increased from 15.70 to 45.50 percent, and for P_{80} treatments increased from 18.99 to 51.96 per cent (Table 1). In Abohar, colonization for the P_{40} treatments increased from 19.75 per cent at 20 DAS to 52.25 per cent at 80 DAS, with the P_0 treatments increasing from 11.72 per cent to 41.38 per cent, (Table 2). Similarly, in Ludhiana, the spore population per 100 grams of rhizospheric soil for the P_{40} treatments increased from 235.41 spores at 20 DAS to 574.67 sporesat 80 DAS, while in P_0 treatments increased from 168.75 spores to

417.00 spores, and in P_{80} increased from 193.75 spores to 500.33 spores (Table 3). In Abohar, the spore population for P_{40} treatments increased from 179.17 spores at 20 DAS to 482.92 spores at 80 DAS, with the P_0 treatment increasing from 118.75 spores to 395.83 spores, and in P_{80} treatment rising from 137.50 spores to 435.42 spores (Table 4). These results indicate that phosphorus application, particularly at 40 mg phosphorus/kg soil, significantly enhances AMF colonization and spore population over time in both Ludhiana and Abohar.

Singh et al. (2017) demonstrated that phosphorus levels significantly influenced the mycorrhization of AMF *G. bagyarajii* in the presence and absence of the pathogen *F. oxysporum* f. sp. *ciceri*. Singh et al. (2019) observed that an optimal phosphorus level (40mg/kg of soil) plays a crucial role in enhancing mycorrhizal colonization and spore population of *Glomus macrocarpon* even in the presence of the dry root rot pathogen *Macrophomina phaseolina* in mungbean.

Interaction between mycorrhiza and pathogen: There was a significant interaction between mycorrhiza and the pathogen, particularly influenced by phosphorus application. Among the arbuscular mycorrhiza-inoculated (AMF) treatments, the highest root colonization was consistently observed, with the most significant enhancement occurring at 40 mg phosphorus/kg of soil (P_{40}) compared to both no phosphorus (P_0) and high phosphorus (P_{80}) levels. Specifically, in Ludhiana, AMF colonization increased from 37.31 per cent at 20 DAS to 82.17 per cent at 80 DAS, while in Abohar, it increased from 31.22 per cent at 20 DAS to 79.80 per cent at 80 DAS under P_{40} treatment conditions. The presence of the pathogen reduced AMF root colonization percentages at all three levels of phosphorus, but there was a significant increase in root colonization even in the presence

Table 1. Colonization of *Gigaspora margarita* in roots of pea plants in the presence and absence of *Fusarium oxysporum* f. sp. *pisi* at Ludhiana

Treatment	Colonization percentage after days of sowing			
	20	40	60	80
Mycorrhizal effect				
AMF	30.48 (33.49)	48.89 (44.35)	65.28 (53.88)	74.72 (59.80)
AMF/Pathogen	25.68 (30.43)	40.56 (39.53)	57.67 (49.39)	67.67 (55.33)
Pathogen/AMF	21.05 (27.29)	33.06 (35.07)	51.56 (45.87)	61.56 (51.66)
Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
CD (p=0.05)	0.89	1.62	0.86	0.89
Phosphorus Effect				
P_0	15.70 (23.33)	26.25 (30.80)	40.25 (39.36)	45.50 (42.40)
P_{40}	23.20 (28.78)	35.63 (36.36)	47.66 (43.65)	55.50 (48.14)
P_{80}	18.99 (25.82)	30.00 (33.16)	42.96 (40.94)	51.96 (46.10)
CD (p=0.05)	0.98	2.04	0.49	0.46
Interaction effect between mycorrhiza and pathogen				
P_0 AMF	25.37 (30.23)	42.5 (40.67)	58.67 (49.97)	65.67 (54.11)
P_{40} AMF	37.31 (37.63)	58.33 (49.79)	72.83 (58.58)	82.17 (65.00)
P_{80} AMF	28.76 (32.33)	45.83 (42.57)	64.33 (53.32)	76.33 (60.90)
P_0 AMF/Pathogen	20.27 (26.75)	33.33 (35.24)	54.67 (47.33)	61.67 (51.74)
P_{40} AMF/Pathogen	30.94 (33.78)	47.5 (43.55)	61.67 (51.73)	72.67 (58.47)
P_{80} AMF/Pathogen	25.82 (30.52)	40.83 (39.60)	56.67 (48.81)	68.67 (55.94)
P_0 Pathogen/AMF	17.16 (24.43)	29.17 (32.67)	47.67 (43.64)	54.67 (47.66)
P_{40} Pathogen/AMF	24.57 (29.69)	36.67 (37.24)	56.17 (48.53)	67.17 (55.03)
P_{80} Pathogen/AMF	21.41 (27.54)	33.33 (35.24)	50.83 (45.46)	62.83 (52.42)
P_0 Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
P_{40} Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
P_{80} Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
CD (p=0.05)	(1.57)	1.79	1.29	1.30

of the pathogen at P_{40}. In the treatment AMF/Pathogen and there was an increment in root colonization from 30.94 per cent at 20 DAS to 72.67 per cent at 80 DAS in Ludhiana (Table 1) and from 26.81 per cent at 20 DAS to 68.21 per cent at 80 DAS in Abohar (Table 3) under P_{40} conditions. Whereas in Pathogen/AMF treatment, the AMF colonization increased from 24.57 per cent at 20 DAS to 67.17 per cent at 80 DAS in Ludhiana and from 20.99 per cent at 20 DAS to 60.98 per cent at 80 DAS in Abohar under P_{40} conditions. The interaction effect on the spore population of AMF *Gigaspora margarita* in the 100 grams of rhizospheric soil were also significant. At the P_{40} level, the AMF alone treatment showed the highest spore population increase from 391.67 spores at 20 DAS to 864.33 spores at 80 DAS in Ludhiana (Table 2) and from 333.33 spores at 20 DAS to 756.67 spores at 80 DAS in Abohar (Table 4).

In AMF/Pathogen treatment, the spore population increased from 291.67 spores at 20 DAS to 763.33 spores at 80 DAS in Ludhiana and from 216.67 spores at 20 DAS to 583.33 spores at 80 DAS in Abohar, whereas in Pathogen/AMF, the spore population increased from 258.33 spores at 20 DAS to 670.33 spores at 80 DAS in Ludhiana and from 166.67 spores at 20 DAS to 516.67 spores at 80 DAS in Abohar. No AMF spores were found in the treatment where only the pathogen was present at both locations. Pre-application of AMF with optimal phosphorus levels significantly increased both colonization and spore population in the presence of the pathogen, compared to post-application, as it fostered a stronger symbiotic relationship with the plants. Taffouo et al. (2014) demonstrated that cowpea plants receiving less phosphorus exhibited greater root colonization than those receiving more phosphorus, observed during both vegetative and pod-filling stages. Temegne et al. (2017) observed that mycorrhization

Table 2. Colonization of *Gigaspora margarita* in roots of pea plants in the presence and absence of *Fusarium oxysporum* f. sp. *pisi* at Abohar

Treatment	Colonization percentage after days of sowing			
	20	40	60	80
Mycorrhizal effect				
AMF	25.71 (30.45)	38.27 (38.20)	55.00 (17.85)	71.45 (57.68)
AMF/Pathogen	20.88 (27.18)	32.75 (34.89)	48.00 (43.84)	61.44 (51.59)
Pathogen/AMF	17.04 (24.37)	28.12 (32.01)	40.75 (39.65)	55.30 (48.02)
Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
CD (p=0.05)	0.76	0.73	0.70	0.60
Phosphorus Effect				
P_0	11.72 (20.01)	19.96 (26.52)	30.02 (33.21)	41.38 (40.02)
P_{40}	19.75 (26.37)	29.01 (32.57)	40.79 (39.68)	52.25 (46.27)
P_{80}	16.24 (23.76)	25.38 (30.24)	36.71 (37.31)	47.52 (43.56)
CD (p=0.05)	0.92	0.72	0.65	0.47
Interaction effect between CD (p=0.05)				
P_0 AMF	20.95 (27.22)	31.40 (34.07)	47.25 (43.41)	61.72 (51.76)
P_{40} AMF	31.22 (33.94)	45.09 (42.16)	62.25 (52.08)	79.80 (63.31)
P_{80} AMF	24.95 (29.95)	38.31 (38.22)	55.75 (48.28)	72.84 (58.57)
P_0 AMF/Pathogen	14.32 (22.22)	25.82 (30.52)	39.25 (38.78)	54.29 (47.44)
P_{40} AMF/Pathogen	26.81 (31.16)	38.55 (38.36)	55.50 (48.14)	68.21 (55.66)
P_{80} AMF/Pathogen	21.51 (27.62)	33.87 (35.58)	48.50 (4.12)	61.83 (51.82)
P_0 Pathogen/AMF	11.62 (19.92)	22.62 (28.38)	34.00 (35.65)	49.51 (44.70)
P_{40} Pathogen/AMF	20.99 (27.24)	32.40 (34.68)	45.50 (42.40)	60.98 (51.98)
P_{80} Pathogen/AMF	18.52 (25.46)	29.35 (32.79)	42.50 (40.67)	55.40 (48.08)
P_0 Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
P_{40} Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
P_{80} Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
CD (p=0.05)	1.20	0.94	0.93	0.98

intensity in *Voandzou* as highest at 30mg of P_2O_5, while higher phosphorus doses did not significantly influence mycorrhization frequency.

Effect of AMF *Gigaspora margarita* on fusarium wilt of pea: At 20 DAS, 100 per cent disease inhibition was observed in the AMF/pathogen treatment across all phosphorus levels in both locations. In the pathogen/AMF treatment, disease inhibition percentages of 90.00, 93.34 and 86.66 were recorded at P_0, P_{40} and P_{80} in Ludhiana (Table 5), respectively. Similarly, in Abohar disease inhibition percentages were 83.33, 93.33 and 80.00 at the same phosphorus levels (Table 6). Plants inoculated solely with the pathogen died at the seedling stage across all phosphorus levels. In treatments with only AMF, 100 per cent of AMF-inoculated plants remained healthy throughout all four observations during the crop season. At 40 DAS, disease inhibition percentages in the AMF/pathogen treatment were 90.00, 96.67 and 86.67 in Ludhiana, and 80, 83.33 and 73.33 in Abohar at P_0, P_{40} andP_{80}, respectively.

At 60 DAS, the AMF/pathogen treatment showed disease inhibition percentages of 83.34, 93.34and 76.67 in Ludhiana, and 76.67, 80.00 and 70.00 in Abohar at P_0, P_{40} and P_{80}, respectively. The pathogen/AMF treatment per cent disease inhibition of 76.67, 83.33 and 70.00 inhibition in Ludhiana, and 66.67, 70.00 and 60.00 in Abohar for the same phosphorus levels. At 80 DAS, the AMF/pathogen treatment showed disease inhibition of 76.67 per cent at P_0, 86.67 at P_{40} and 66.67 per cent at P_{80} in Ludhiana, while in Abohar, the disease inhibition of 70.00 per cent, 73.33 per cent and 66.67 per cent at the corresponding phosphorus levels.

The present findings were corroborated with study conducted by Singh et al. (2019) which indicated that dual inoculation of AMF and pathogen in the presence of phosphorus reduced dry root rot disease intensity in

Table 3. Spore population of *Gigaspora margarita* in rhizosphere of pea plants in the presence and absence of *Fusarium oxysporum* f. sp. *pisi* at Ludhiana

Treatment	Spore population observed after days of sowing			
	20	40	60	80
Mycorrhizal effect				
AMF	333.33	512.78	670.44	778.67
AMF/Pathogen	252.78	441.78	558.02	650.67
Pathogen/AMF	211.11	340.17	422.93	560.67
Pathogen	0.00	0.00	0.00	0.00
CD (p=0.05)	15.26	4.95	6.56	7.67
Phosphorus Effect				
P_0	168.75	236.46	331.00	417.00
P_{40}	235.41	422.75	502.00	574.67
P_{80}	193.75	311.83	405.67	500.33
CD (p=0.05)	13.42	4.39	5.92	7.02
Interaction effect between CD (p=0.05)				
P_0 AMF	291.67	401.00	561.00	673.67
P_{40} AMF	391.67	626.67	786.00	864.33
P_{80} AMF	316.67	510.67	664.00	796.67
P_0 AMF/Pathogen	216.67	317.33	444.67	533.33
P_{40} AMF/Pathogen	291.67	588.00	684.00	763.33
P_{80} AMF/Pathogen	250.00	420.00	546.00	655.33
P_0 Pathogen/AMF	166.67	227.50	318.67	461.33
P_{40} Pathogen/AMF	258.33	476.33	538.67	670.33
P_{80} Pathogen/AMF	208.33	316.67	411.67	550.00
P_0 Pathogen	0.00	0.00	0.00	0.00
P_{40} Pathogen	0.00	0.00	0.00	0.00
P_{80} Pathogen	0.00	0.00	0.00	0.00
CD (p=0.05)	19.98	7.04	9.44	10.85

Table 4. Spore population of *Gigaspora margarita* in rhizosphere of pea plants in the presence and absence of *Fusarium oxysporum* f. sp. *pisi* at Abohar

Treatment	Spore population observed after days of sowing			
	20	40	60	80
Mycorrhizal effect				
AMF	258.33	422.22	536.11	660.56
AMF/Pathogen	186.11	344.45	444.44	544.44
Pathogen/AMF	136.11	291.67	380.56	472.22
Pathogen	0.00	0.00	0.00	0.00
CD (p=0.05)	21.73	15.03	7.85	17.33
Phosphorus Effect				
P_0	118.75	229.17	304.17	395.83
P_{40}	179.17	308.33	379.17	482.92
P_{80}	137.50	256.25	337.50	435.42
CD (p=0.05)	11.02	13.81	5.88	7.49
Interaction effect between mycorrhiza and pathogen				
P_0 AMF	208.33	358.33	466.67	583.33
P_{40} AMF	333.33	516.67	616.67	756.67
P_{80} AMF	233.33	391.67	525.00	641.67
P_0 AMF/Pathogen	158.33	308.33	408.33	491.67
P_{40} AMF/Pathogen	216.67	383.33	483.33	583.33
P_{80} AMF/Pathogen	183.33	341.67	441.67	558.33
P_0 Pathogen/AMF	108.33	250.00	341.67	433.33
P_{40} Pathogen/AMF	166.67	333.33	416.67	516.67
P_{80} Pathogen/AMF	133.33	291.67	383.33	466.67
P_0 Pathogen	0.00	0.00	0.00	0.00
P_{40} Pathogen	0.00	0.00	0.00	0.00
P_{80} Pathogen	0.00	0.00	0.00	0.00
CD (p=0.05)	21.07	19.86	19.86	21.34

Table 5. Effect of *Gigaspora margarita* inoculation on development of pea wilt caused by *Fusarium oxysporum* f. sp. *pisi* at various stages of plant growth and phosphorus level at Ludhiana

Phosphorus level	Treatments	Disease Inhibition % observed after days of sowing			
		20 days	40 days	60 days	80 days
P_0	AMF	100.00(89.96)	100.00(89.96)	100.00(89.96)	100.00(89.96)
	AMF/Pathogen	100.00(89.96)	90.00(74.92)	83.34(66.12)	76.67(61.20)
	Pathogen/AMF	90.00(74.92)	83.33(66.12)	76.67(61.90)	66.67(54.76)
	Pathogen	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
	CD (p=0.05)	7.31	7.81	3.26	5.51
P_{40}	AMF	100.00(89.96)	100.00(89.96)	100.00(89.96)	100.00(89.96)
	AMF/Pathogen	100.00(89.96)	96.67(83.82)	93.34(77.68)	86.67(68.83)
	Pathogen/AMF	93.34(77.68)	90.00(74.92)	83.33(66.12)	73.33(58.98)
	Pathogen	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
	CD (p=0.05)	5.78	7.88	6.31	5.05
P_{80}	AMF	100.00(89.96)	100.00(89.96)	100.00(89.96)	100.00(89.96)
	AMF/Pathogen	100.00(89.96)	86.67(68.83)	76.66(61.20)	66.67(54.76)
	Pathogen/AMF	86.66(68.83)	76.67(61.90)	70.00(56.77)	60.00(50.75)
	Pathogen	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
	CD (p=0.05)	6.26	6.6	3.19	2.94

Table 6. Effect of *Gigaspora margarita* inoculation on development of pea wilt caused by *Fusarium oxysporum* f. sp. *pisi* at various stages of plant growth and phosphorus level at Abohar

Phosphorus level	Treatments	Disease Inhibition % observed after days of sowing			
		20 days	40 days	60 days	80 days
P_0	AMF	100.00 (89.96)	100.00 (89.96)	100.00 (89.96)	100.00 (89.96)
	AMF/Pathogen	100.00 (89.96)	80.00 (63.41)	76.67 (61.2)	70.00 (56.77)
	Pathogen/AMF	83.33 (66.12)	73.33 (58.98)	66.67 (54.76)	60.00 (50.75)
	Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	CD (p=0.05)	3.73	4.52	5.74	4.02
P_{40}	AMF	100.00 (89.96)	100.00 (89.96)	100.00 (89.96)	100.00 (89.96)
	AMF/Pathogen	100.00 (89.96)	83.33 (66.12)	80.00 (63.52)	73.33 (58.98)
	Pathogen/AMF	93.33 (77.68)	76.67 (61.69)	70.00 (56.77)	66.67 (54.76)
	Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	CD (p=0.05)	7.26	3.29	5.94	3.69
P_{80}	AMF	100.00 (89.96)	100.00 (89.96)	100.00 (89.96)	100.00 (89.96)
	AMF/Pathogen	96.67 (83.82)	73.33 (58.98)	70.00 (56.77)	66.67 (54.76)
	Pathogen/AMF	80.00 (63.41)	63.33 (52.75)	60.00 (50.75)	53.33 (46.90)
	Pathogen	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	CD (p=0.05)	6.44	4.38	3.32	3.59

mungbean plants by 70 per cent in spring and 86.6 per cent in the *Kharif* season if AMF was present before the pathogen. Sarita et al. (2022) observed 100 per cent wilt disease in chili plants when *Fusarium oxysporum* was inoculated alone, but the disease incidence reduced to 60 per cent when co-inoculated with *G. intraradices*.

CONCLUSION

The results highlight that disease development was lower in plants inoculated with both arbuscular mycorrhizal fungus and pathogen compared to only pathogenic treatment at both locations.

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