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Research Article

Management of *Rhizoctonia solani*, *Fusarium solani* and *Meloidogyne incognita* by Silicon dioxide nanoparticles and *Rhizobium ciceri* alone and in combination on chickpea

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Abstract

Effects of silicon dioxide nanoparticles (SiO_2 NPs) and *Rhizobium ciceri* was observed alone and in combination on *Rhizoctonia solani*/ *Fusarium solani* / *Meloidogyne incognita* on the growth, photosynthetic pigments (chlorophyll and carotenoid) and proline contents of *Cicer arietinum*.

Inoculation of *M. incognita* resulted in a greater reduction in plant growth, photosynthetic pigments and higher increase in proline contents than other test pathogens. Inoculation of *R. ciceri* or foliar spray of SiO_2 NPs (0.10 mg ml^{-1}) with pathogens under study resulted in increased plant growth, photosynthetic pigments and proline contents than without *R. ciceri* / NPs. Combined application of NPs with *R. ciceri* resulted in a greater increase in plant growth, photosynthetic pigments and proline contents in plants with pathogens than with NPs or *R. ciceri*. Plants without *R. ciceri* had a very poor root nodulation but nodulation was high in plants with *R. ciceri*. Pathogens under study and NPs had adverse effect on nodulation caused by *R. ciceri*. Wet rot and black root rot indices were 4 when R. solani and *F. solani* were inoculated respectively. *R. ciceri* / NPs reduced wet root rot, black root rot indices, galling and population of *M. incognita*. Disease indices, galling and population of *M. incognita* were reduced greatly by use of *R. ciceri* plus SiO_2 NPs.

Keywords: Black Root Rot; *Cicer Arietinum*; Disease Index; Root Knot Nematode; Root Nodule Bacterium; Wet Root Rot

Introduction

Chickpea (*Cicer arietinum* L.) is widely grown as major food legume because of its rich nutrient values. It has high protein and starch suitable for textile sizing Duke [6]. *Rhizobium* Frank is root nodule bacterium bacterium associated with roots of legumes for symbiotic nitrogen fixation. *Rhizobium* inoculation has positive effect on growth attributes, yield components and quality of chickpea. Application of rhizobial isolates significantly suppress root rotting fungi and root knot nematode Parveen et al. [20] and reduced damaged caused Siddiqui and Mahmood [23].

Important diseases of chickpea include; Rhizoctonia wet rot (*Rhizoctonia solani* Kuhn) and Fusarium black root rot (*Fusarium solani* Mart. Amend Sacc.) and root-knot disease by *Meloidogyne incognita* (Kofoid and White) Chitwood. Parasitism by *M. incognita* in chickpea involves giant cells formation and root galling Vovlas et al. [29]. Rhizoctonia wet root causes severe losses from seedling to maturity stages Jayalakshmi et al. [12]. Its characteristic symptoms include root rotting and gradual yellowing and wilting of foliage, the rotted, discolored tissues are soft and wet. Fusarium black root rot also results in severe losses to of chickpea crop Jayalakshmi et al. [12]. The root system is generally rotted with most of the finer roots destroyed, while the taproot remains intact, but dark and necrotic.

Silicon (Si) application is useful for increasing plant growth. Use of Si overcome biotic stresses and also improves plant's

physiological and mechanical properties Epstein [7]; Ma and Yamaji [10]. Si also enhances disease resistance against pest and pathogens Marschner [18].

Frequent occurrence of *F. solani*, *R. solani* and *M. incognita* was observed in the chickpea fields of Aligarh, U.P. India. Infected plants were found with symptoms of diseases having poor plant growth. Silicon dioxide nanoparticles (SiO_2 NPs) and *Rhizobium ciceri* were used alone and in combination management of *F. solani*, *R. solani* and *M. incognita* on chickpea. Effects of SiO_2 NPs and *R. ciceri* were also observed on chickpea growth, photosynthetic pigments and also on proline contents.

Materials And Methods

Chickpea fields were surveyed for the collection disease materials of Aligarh U.P. Samples (root and soil) were collected and placed at 4°C until processing in refrigerator. The presence of plant parasitic nematodes and fungi in the collected samples were examined.

Isolation of fungi from infected chickpea

Roots showing disease symptoms were washed with sterilized water three times to remove soil particles. Isolation of fungi was made from infected plant parts Siddiqui et al. [24] on potato dextrose agar (PDA) medium. Identity of *Rhizoctonia solani* and *Fusarium solani* was confirmed. Later, pure cultures were separately prepared of both *R. solani* and *F. solani*

Root-knot nematode *M. incognita*

Root-knot nematodes females were dissected out from roots of chickpea having symptoms of root-knot. Later, perineal patterns were prepared for the identification of *Meloidogyne* sp. Taylor and sasser [27].

Preparation of SiO_2NPs suspension

SiO_2 NPs (Sigma-Aldrich, product No. 637246-50G) was used to prepare 0.10 mg ml^{-1} suspension by dissolving 100 mg nanapowder in 1-liter sterilized water. Foliar spray of 10 ml suspension was made on seedlings (15-day old) in a greenhouse with small spray pumps. Distilled water (10 ml) was sprayed on control plants and each treatment had five replications.

Effect of SiO_2 NPs on *M. incognita*

The effect of SiO_2 NPs was studied on the *M. incognita*. Egg masses (20) of average size from eggplant roots were picked with sterilized forceps and effect of 0.10 mg ml^{-1} NPs on the hatching and mortality was observed as described by Siddiqui et al. [24].

Effect of SiO_2 NPs on the fungi

Activity of SiO_2 NPs against both fungi was observed separately. Ten ml NPs (0.10 mg ml^{-1} conc.) was added in 100 ml autoclaved PDA to observe effect as described by Siddiqui et al. [24]

Preparation and sterilization of soil mixture

Collected loam soil was sieved through 10 meshes. Clay pots were filled with 1 kg of soil mixed with loam soil and river sand (3:1). Before sterilization, soil surface of pots was wet with water, sterilized at 137.9 kPa for 20 minutes and allowed for cooling 24 hours.

Raising and maintenance of test plants

Chickpea (*Cicer arietinum* L.) seeds Pusa-3022 were sterilized and sown in 15 cm pots Siddiqui et al. [24]. Seedlings were inoculated and un-uninoculated control were placed in a glass house at 20 ± 2oC (Table 2). Pots were arranged on a bench and each treatment had five replications. Watering of plants was done as required. Ninety days after inoculation plants were harvested

Inocula of fungi

Richard's liquid medium was used for culturing of both fungi separately Riker and Riker [22] for obtaining inocula. Eighty ml liquid medium after filtration through muslin cloth was placed 250 ml flasks, autoclaved at 103.4 kPa for 15 minutes. Each fungus was separately inoculated, incubated, mycelia mats were collected, blotting sheets were used to remove excess water and inoculum of each fungus was prepared in Waring blender as described Siddiqui et al. [24]. Ten ml of this suspension was used as inculum (1 g fungus).

Nematode inoculum

Infected chickpea roots were used to collect *Meloidogyne incognita*, eggplants for its multiplication. Later, inoculum was prepared, juveniles were counted and 2000 juveniles were inoculated as described by Siddiqui et al. [24]

Rhizobium inoculum

Rhizobium ciceri (100 g) charcoal culture was dissolved in 1 liter sterilized water. Ten ml (1 g inoculum) around the seeds per pot was inoculated where required.

Inoculation technique

Rhizobium ciceri was used with seeds at sowing in about half seeds. Inoculation of *R. solani*, *F. solani* and *M. incognita*, chickpea seedlings (two weeks old) were used and inoculations were done Siddiqui et al. [24]. There were 2 treatments i.e. (1) Control; (2) *Rhizobium ciceri*. Each of these was tested with (I) Control; (II) *R. solani*; (III) *F. solani*; (IV) *M. incognita* (4×2=8). These 8 treatments were tested in two combinations (i) without SiO_2 NPS spray (ii) With SiO_2 NPs spray (8×2= 16). Each treatment had 5 replications (16×5=80 pots).

Evaluation of the experiment

Ninety days after inoculation the plants were harvested. Plant growth attributes, photosynthetic pigments, proline and disease

index, galling and nematode population were recorded Siddiqui et al., [24].

Disease index

Disease index were determined on disease symptoms. Disease rating was done on 0 (no disease) to 5 (severe rot / blight) Nesha and Siddiqui [19]

Estimation of photosynthetic pigments and proline content

Photosynthetic pigments (chlorophyll and carotenoid) in the fresh leaf samples were estimated by Mackinney [17] and proline content by Bates et al. [3].

Statistical analysis

The data were analysed through three ways (*Rhizobium ciceri* × SiO_2 NPs × Pathogens) analysis of variance (ANOVA) in R (version 2.14.0) statistical software (package- library agricolae). Least significant difference (L.S.D) were calculated at p=0.05. Duncan's new multiple range test (DNMRT) were employed to denote the significant differences between treatments. Graphs of nematode population and galls per root system were prepared using Sigma Plot™ and error bars showing standard error.

Results

Effects on SiO_2 NPS on pathogenic fungi and on *M. incognita*

Effects of SiO_2 NPs were studied on *R. solani* and *F. solani* (Table 1). It had a higher adverse effect on the growth of *F. solani* followed by *R. solani*. SiO_2 NPs caused 36.25 and 34.60% inhibitions in the growth of *F. solani* and *R. solani* respectively (Table 1). SiO_2 NPs also had adverse effect on the hatching of *M. incognita*. It caused 88.37% inhibition in hatching of *M. incognita* while 43.75% mortality of *M. incognita* J2 was observed after 48 hours of incubation over control (Table 1).

Table 1: Effect of SiO_2 NPs on the growth of *F. solani* and *R. solani* in potato dextrose agar medium and on the hatching and mortality of *M. incognita*.

Nanoparticles	Concentration	Fusarium solani	
		Colony diameter (cm)	% inhibition over control
Control	DDW	8.00 a	-
SiO_2 NPs	0.10 mg ml^{-1}	5.10 b	36.25
L.S.D. P≤0.05		0.44	-
Nanoparticles	Concentration	Hatching of *M. incognita* J2	% inhibition over control
Control	DDW	215 a	-
SiO_2 NPs	0.10 mg ml^{-1}	19 b	88.37

Pot experiment

Three ways ANOVA revealed that individual effect of *Rhizobium ciceri*, SiO_2 NPs and pathogen, and interaction of *R. ciceri* × SiO_2 NPs, Pathogen × *R. ciceri*, SiO_2 NPs × pathogen and *R. ciceri* × SiO_2 NPs × pathogen was significant in proline content and root nodulation at p=0.05 (ANOVA not shown). However, effect of interaction of *R. ciceri* × SiO_2 NPs × pathogen on shoot length, root fresh weight, root dry weight and photosynthetic pigments was non-significant at p=0.05. Similarly, effect of interaction of Pathogen × *R. ciceri* on root length, shoot fresh weight, shoot dry weight, root dry weight, chlorophyll was also non-significant at p=0.05. Effect of interaction on SiO_2 NPs × pathogen on shoot fresh weight, root dry weight and photosynthetic pigments were also non-significant at p=0.05. However, Individual effect of *R. ciceri*, SiO_2 NPs and pathogen and their interactions were significant on other parameters studied (ANOVA not shown).

Effect on plant growth and nodulation

Inoculation of plants with pathogens under study i. e. *M. incognita*, *F. solani* and *R. solani* resulted in a significant reduction in plant growth parameters over uninoculated control (Table 2). Inoculation of *M. incognita* resulted in a higher reduction (26.07%) in shoot dry weight followed by *R. solani* (23.92%) and *F. solani* (20.10%). Similarly, inoculation of *M. incognita* resulted in a higher reduction (25.42%) in root dry weight followed by *R. solani* (23.73%) and *F. solani* (20.33%). Plants without *R. ciceri* had poor nodulation while plants with *R. ciceri* had higher nodulation (Table 2).

Foliar spray of SiO_2 NPs resulted in a significant increase in plant growth parameters over plants with and without pathogen (Table 2). Spray of SiO_2 NPs to plants without pathogen caused 25.36% increase in shoot dry weight over uninoculated control. Foliar spray of SiO_2 NPs to plants with *M. incognita* caused 33.01% increase in shoot dry weight while plants with *F. solani* and *R. solani* resulted in 39.22% and 39.31% increase in shoot dry weight over plants with respective pathogen alone (Table 3). Foliar spray of SiO_2 NPs caused 38.98% increase in root dry weight over uninoculated control. Spray of SiO_2 NPs to plants with *M. incognita*, *F. solani* and *R. solani* resulted in 45.45%, 53.19% and 53.33% increase in root dry weight respectively. Nodulation in plants without *R. ciceri* remain unaffected by inoculation of pathogens and SiO_2 NPs spray because of very poor nodulation (Table 2).

Table 2: Effects of SiO_2 NPs and *Rhizobium ciceri* alone and both together on *F. solani, R. solani* and *M. incognita* and on the growth attributes and nodulation of chickpea.Values within a column followed by the same letter are not significantly different at p=0.05 by DNMRT.

Treatment			Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)	No of nodules / root system
Nil	Nil	C	48.6cd	16.0gh	14.37h	6.90l	4.18hi	0.59g	4g
		M	35.8i	12.2l	11.01j	4.93n	3.09k	0.44h	3gh
		F	40.0h	13.9j	12.31i	5.29m	3.34j	0.47h	3gh
		R	38.2h	12.7k	11.39j	5.20m	3.18jk	0.45h	2h
	SiO_2 NPs Spray	C	51.2ab	18.4d	16.65f	9.08g	5.24d	0.82cd	3gh
		M	44.4g	15.2i	14.19h	7.19k	4.11i	0.64fg	4g
		F	46.0efg	16.3g	15.09g	7.92i	4.65f	0.72def	3gh
		R	45.2fg	15.8h	14.49h	7.50j	4.43fg	0.69efg	3gh
Rhizobium ciceri	Nil	C	50.4bc	18.8cd	20.20c	10.77e	5.26d	0.85c	46a
		M	44.2g	16.0gh	17.52e	8.63h	4.35gh	0.70ef	36c
		F	45.8efg	17.8e	18.40d	9.57f	5.02e	0.79cde	32d
		R	44.6g	16.8f	18.13d	9.21g	4.62f	0.75cde	29e
	SiO_2 NPs Spray	C	53.0a	21.8a	22.93a	13.18a	8.77a	1.30a	42b
		M	47.2def	18.7cd	19.97c	11.19d	7.29c	1.05b	31d
		F	48.2cde	19.3b	20.92b	12.35b	7.92b	1.14b	28e
		R	47.8de	18.9bc	20.05c	12.08c	7.44c	1.09b	24f
LSD p=0.05			2.21	0.45	0.41	0.24	0.21	0.09	1.67

Table 3: Effects of SiO_2 NPs and *Rhizobium ciceri* alone and both together on *F. solani, R. solani* and *M. incognita* and on the photosynthetic pigments (chlorophyll and carotenoid) proline content and disease index of chickpea.

Treatments			Total chlorophyll (mg/FW)	Carotenoids content (mg/FW)	Proline content (µmol/g FW)	Root rot disease index
Nil	Nil	C	0.198g	0.0675h	0.0024l	-
		M	0.136i	0.0501j	0.0052jk	-
		F	0.186gh	0.0640hi	0.0028l	4
		R	0.174h	0.0606i	0.0047k	4
	SiO_2 NPs Spray	C	0.236de	0.0880ef	0.0104g	-
		M	0.201fg	0.0687h	0.0171e	-
		F	0.226e	0.0860f	0.0107g	3
		R	0.219ef	0.0783g	0.0139f	3
Rhizobium ciceri	Nil	C	0.259c	0.1002c	0.0061ij	-
		M	0.237de	0.0893def	0.0094gh	-
		F	0.257c	0.0940d	0.0068i	3
		R	0.248cd	0.0917de	0.0083h	3
	SiO_2 NPs Spray	C	0.288a	0.1127a	0.0184d	-
		M	0.264bc	0.1022bc	0.0331a	-
		F	0.286a	0.1059b	0.0234c	2
		R	0.283ab	0.1041bc	0.0268b	2
LSD p=0.05			0.020	0.005	0.001	-

Values within a column followed by the same letter are not significantly different at p=0.05 by DNMRT.

Inoculation of *R. ciceri* resulted in a significant increase in plant growth parameters over pathogen inoculated and un-inoculated control (except shoot length in uninoculated plants) (Table2). Inoculation of *R. ciceri* resulted in 25.84% increase in shoot dry weight over uninoculated control. Use of *R. ciceri* to plants with *M. incognita*, *F. solani* and *R. solani* resulted in 40.78, 50.30 and 45.28% increase in shoot dry weight respectively over their respective inoculated control (Table 2). Inoculation of *R. ciceri* caused 44.06% increase in root dry weight over uninoculated control. Similarly, chickpea plants grown with *R. ciceri* and with *M. incognita*, *F. solani* and *R. solani* resulted in 59.09, 68.09 and 66.67% increases in root dry weight over respective pathogen inoculated plants. High root nodulation was observed in plants with *R. ciceri* while pathogens under study had adverse effect on root nodulation caused by *R. ciceri* (Table 2).

Foliar spray of SiO_2 NPs together with *R. ciceri* caused a highest increase in plant growth parameters over both un-inoculated and pathogen inoculated control (Table 2). Spray of SiO_2 NPs with *R. ciceri* resulted in 109.80% increase in shoot dry weight over control. Similarly, spray of SiO_2 NPs plus inoculation of *R. ciceri* to plants with *M. incognita*, *F. solani* and *R. solani* caused 139.92, 137.13 and 133.96% increase in shoot dry weight over their respective inoculated control (Table 2). Use of *R. ciceri* with SiO_2NPs resulted in 120.33% increase in root dry weight over control. However, spray of SiO_2NPs to plants with *R. ciceri* and test pathogens i.e. *M. incognita*, *F. solani* and *R. solani* resulted in 138.64, 142.55 and 142.22% increase in root dry weight over respective control. Pathogen under study had adverse effect on root nodulation caused by with *R. ciceri* and spray of SiO_2 NPs also adversely affect root nodulation (Table 2).

Effect on photosynthetic pigments

Inoculation of plants with *M. incognita*, and *R. solani* caused a significant reduction in photosynthetic pigments i. e. chlorophyll and carotenoid contents over uninoculated plants (Table 3). Foliar spray of SiO_2 to plants with pathogens under study caused a significant increase in photosynthetic pigments over plants with pathogen alone. Foliar application of SiO_2 caused 19.19 and 30.37% increases in chlorophyll and carotenoid respectively over control. Similarly, foliar spray of SiO_2 to plants with *M. incognita*, *R. solani* and *F. solani* resulted in 21.50 to 47.79% increase in chlorophyll and 29.21 to 37.13% increase in carotenoid over respective inoculated control. Inoculation of *R. ciceri* caused 30.80 and 48.44% increase in chlorophyll and carotenoid respectively over control. Similarly, *R. ciceri* inoculation to plants with *M. incognita*, *R. solani* and *F. solani* resulted in 42.53 to 74.26% increase in chlorophyll and 46.88 to 78.24% increase in carotenoid contents. Combined use of *R. ciceri* together with SiO_2 NPs caused 45.45 and 66.96% increase in chlorophyll and carotenoid respectively over control. Similarly, use of *R. ciceri* with SiO_2 NPs to plants with *M. incognita R. solani* and *F. solani* caused 53.76 to 94.11% increase in chlorophyll and 65.47 to 103.99% increase in carotenoid contents (Table 3).

Effect on proline contents

A significant increase in proline contents was observed in plants with *M. incognita*, *F. solani* and *R. solani* over control (Table 3). Plants with *M. incognita*, caused a higher increase in proline contents than by *F. solani*. Foliar spray of SiO_2 or inoculation of *R. ciceri* also increased proline contents. Use of SiO_2 NPs together with *R. ciceri* resulted in highest increase in proline contents over other treatments (Table 3).

Disease indices

Wet root rot and black root rot disease indices were found 4 in plants with *R. solani* and *F. solani* respectively (Table 3). Disease indices were 3 in plants with *R. solani* / *F. solani* and sprayed with SiO_2 NPs or inoculated with *R. ciceri*. Combined use of SiO_2 NPs with *R. ciceri* reduced disease indices to 2 (Table 3).

Root galling and nematode population

Inoculation of *M. incognita* inoculated alone resulted in high root galling and nematode population (Figure 1, 2). Foliar spray of SiO_2NPs or inoculation of *R. ciceri* reduced galling and nematode population. SiO_2NPs spray caused a higher reduction in galling and nematode population as compared to *R. ciceri* inoculation. Spray of SiO_2NPs together with *R. ciceri* caused highest reduction in nematode population and galling (Figure 1, 2).

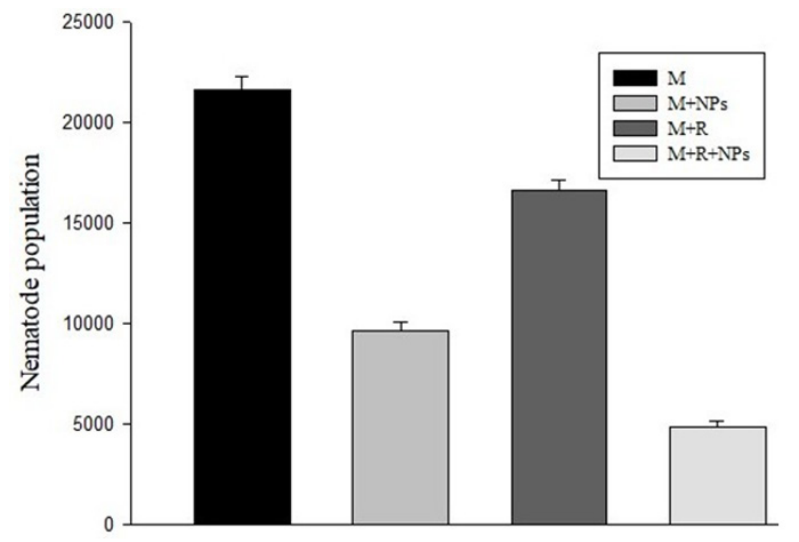

Figure 1: Effect of SiO_2 NPs (NPs) and *Rhizobium ciceri* (R) on the population of *M. incognita* (M) on chickpea.

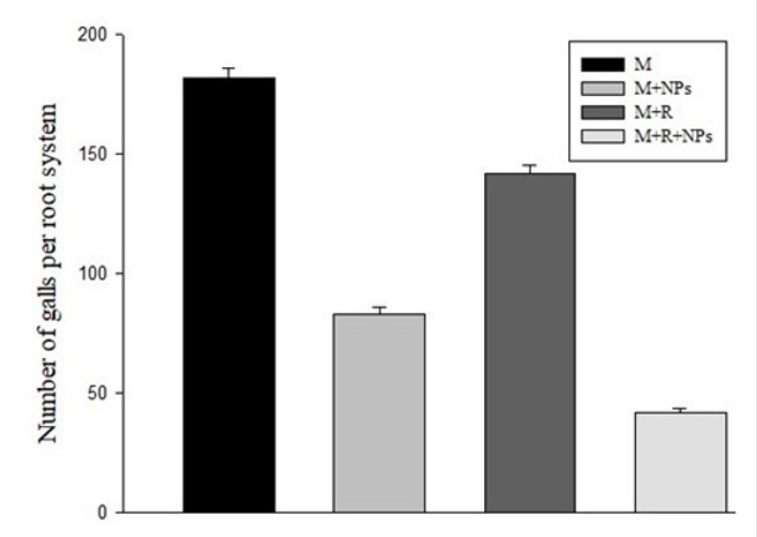

Figure 2: Effect of SiO_2 NPs (NPs) and *Rhizobium ciceri* (R) on the galling of *M. incognita* (M) on chickpea.

Discussion

SiO_2 NPs showed antifungal effect in PDA medium because growth of *R. solani*, and *F. solani* was inhibited. Similarly, Akpinar et al. [1] found that SiO_2 NPs resulted in maximum inhibition of *F. oxysporum* f. sp. radicis lycopersici. SiO_2 NPs also showed adverse effect on *M. incognita* J2 hatching. Observation of hatched J2 showed straight body shape and intake of NPs in J2 of *M. incognita* within 48 h of incubation. Silica nanoparticles caused degeneration of reproductive organs of nematodes Pluskota et al. [21]. The silicon carbide nanoparticles had lethality as dead nematodes exhibited black internal organs Al Banna et al. [2]. It is possible that SiO_2 NPs taken by the nematodes were translocated to primary and secondary organs Wu et al. [32]; Al Banna et al. [2] resulting in deformation of J2 of *M. incognita*.

In pot experiment, foliar spray of SiO_2 NPs increased growth, chlorophyll and carotenoids contents over uninoculated control. Application of Si in plants results in its accumulation and exerts various beneficial effects on plants Liang et al. [14]. Absorbed Si alleviates various abiotic stresses Wang et al. [31]. Si contributes to overcome stresses also may improves plant's mechanical and physiological properties Epstein [7]; Ma and Yamaji [16]. Increased growth of plants without pathogen (uninoculated control) by SiO_2 application can be due to above reasons.

Foliar spray of SiO_2 NPs increased growth attributes of plants with pathogen. Applications of Si provide resistance against diseases Fauteux et al. [8]; Marschner [18]. Various mechanisms are involved plant disease resistance i.e. defense barriers after pathogen infection, activation enzymes (defense-related), production of antimicrobial compounds and regulation of genes Wang et al. [31]. Si mediated resistance against pathogens was associated with the changes in activity of soil enzyme and soil microorganisms Wang et al. [31]. Silicon amendment also reduced disease incidence of tomato Diogo and Wydra [5].

Foliar spray of SiO_2 can prevent pathogen penetration by formation of a cuticle-Si double layer and decrease disease incidence Ma and Yamaji [16]. Most Si improves mechanical properties and regeneration by cross-linking with hemicellulose in cell walls Guerriero et al. [11].

Proline contents were found to be increased by the spray of SiO_2 NPs in this study. Proline is known to confer tolerance to plants Lehmann et al. [13]. It is a multi-functional amino acid and accumulation of proline acts as a major stress response against pathogens Grote et al. [10]. A correlation between increase in proline contents and increase defense response against pathogens Cecchini et al. [4] has been observed. Increased proline content was also observed in Arabidopsis thaliana Verslues and Sharma [28] in plant defense against pathogen. Therefore, in this study increase in proline contents in plants with pathogen was also observed.

Disease indices were found 4 in plants with fungal pathogens viz. *R. solani* and *F. solani*. Foliar spray of SiO_2 reduced disease indices to 2. Reduction in disease indices by application of SiO_2 also confirms antifungal nature of SiO_2. SiO_2 NPs demonstrated its nematicidal activity by reduction in galling and nematode population. *R. ciceri* also showed antifungal and nematicidal activity by reducing disease indices, galling and *M. incognita* population therefore, increase in plant growth. Rhizobial strains have biocontrol properties and can lead to potential control Gopalkrishnan et al. [9]. *Rhizobium* enhanced resistance level against pathogen by inducing changes in seed proteome and metabolome Sistani et al. [26]. Foliar application of SiO_2 NPs had mild adverse effect on rhizobial root nodulation while combined application of NPs and *R. ciceri* reduce disease severity. This may be possible because of least concentration NPs used as foliar spray. The influence of broad-spectrum of even pesticides and their tolerance to the rhizobia are reported Singh and Wright [25]. It is possible that the *R. ciceri* used in the present study may have tolerance to SiO_2 NPs thereby resultant increase in growth attributes, chlorophyll, carotenoid and proline contents.

Conclusion

SiO_2 NPs had displayed antifungal and nematicidal activities towards tested fungi and root knot nematode. Similarly, *R. ciceri* also provided biocontrol of *M. incognita* and root rot fungi. Use of SiO_2 NPs with *R. ciceri* was better for the management of pathogens under study than their use alone. Therefore, researches on characterizing of resistant rhizobia are needed so they can be used for the management of chickpea diseases along with SiO_2 NPs.

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