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Influence of Arbuscular mycorrhizal fungi on growth, nutrient uptake and disease suppression of some selected vegetable crops

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ABSTRACT

A reduction of the agrochemicals input along with selecting suitable cultivars and species is imperative to increase the sustainability of crop production. The influence of Arbuscular Mycorrhizal Fungi (AMF) on seedling emergence growth, nutrient uptake and disease incidence of some selected vegetables viz. Okra (*Abelmoschus esculentus*), Tomato (*Lycopersicon esculentum*), Brinjal (*Solanum melongena*), Chilli (*Capsicum frutescens)* and Data (*Amaranthus oleraceus*) has been evaluated. The results showed that AMF inoculation could increase almost all growth parameters. The seedling emergence, plant height, length and weight of root and shoot of mycorrhiza inoculated vegetables were comparatively higher than that of non-inoculated control plants. The mycorrhizal inoculation suppressed root rot, damping off and leaf spot disease of Okra, Tomato, Brinjal, Chilli and Data almost to half extent. Meanwhile, an increased nutrient (N, P, K, Fe, and Zn) uptake was recorded with the inoculated plants. Among the inoculated vegetables, comparatively higher N, P, and K uptake were observed in Okra and Brinjal whereas Zn and Fe uptake was found higher in Okra and Data respectively. Therefore, for sustainable vegetable production, introducing bio-fertilizer by using arbuscular mycorrhiza inoculation would be one of the most efficient techniques for replacing chemical fertilizer to meet the nutrient deficiency in nutrient deficient soils.

INTRODUCTION

Over the last two decades, organically grown vegetables have generated significant interest among the consumers and scientists due to healthier products and safer characteristics to human health. Consumers demand for organic vegetables has also on the rise. Therefore, sustainability of vegetable production with higher yield is the prime need to meet consumer demand. Furthermore, sustainable vegetable production has been often reported as an environmentally-friendly production system able to produce food with minimal hazardous effect to ecosystems and environment as well as minimal use of off-farm resources (Dorais 2007). However, the major drawback of organic vegetable production is the lower yield compared to conventional agriculture (Seufert et al. 2012; Dorais and Alsanius 2015). Meanwhile, availability of nutrient (N and P) has been identified to be a major yield-limiting factor in many organic production systems. Therefore, farmers prefer to use commercial synthetic chemical fertilizers for vegetable production. However, excessive use of inorganic fertilizer may lead to environmental pollution including contamination of groundwater, and soil acidification as well as increase de-nitrification resulting in higher the emission of nitrous oxide (N_2O) to the atmosphere which is responsible for global warming. In addition to this, disease incidence is severe in organic vegetable production which is another hurdle for production and cause a considerable damage to the yield. Therefore, there is an urgent need to bring new tools to increase nutrient availability, plant uptake and assimilation, reduce disease intensity in order to close the gap between organic and conventional yields (Barbieri et al. 2015; Rouphael et al. 2015; De Pascale et al. 2016). In recent years, several technical and

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technological innovations were proposed in order to improve the sustainability of production systems, through a significant reduction of agrochemicals. A promising practice would be the use of substances and/or microorganisms that enhance plant growth, increase tolerance to disease and environmental conditions, and also improve the resource use efficiency. Inoculation of Arbuscular mycorrhizal fungi (AMF) can be promising in soil and disease management to achieve low-cost sustainable vegetable production systems. AMF are intrarradical mycorrhizae that colonize the tissue of the host plant, where they develop structures characteristic of the symbiosis as well as extraradical and mycelium, which interacts with the ecosystem of the rhizosphere and is responsible for making soil nutrients available (Sosa et al. 2006). The symbiotic root-fungal association increases the uptake of less mobile nutrients (Ortas et al. 2001), essentially phosphorus (P) but also of micronutrients like zinc (Zn) and copper (Cu), the symbiosis has also been reported as influencing water uptake. AMF can also benefit plants by stimulating the production of growth regulating substances, increasing photosynthesis, improving osmotic adjustment under drought and salinity stresses and increasing resistance to pests and soil borne diseases (Al-Karaki 2006). Considering the above perspective, the present experiment was carried out to evaluate the influence of AMF on growth, nutrient uptake and disease suppression of disease intensity of some selected vegetable crops to find out their potentiality as bio-fertilizer.

MATERIALS AND METHODS

Study area

The experiment was conducted in the net house and in the seed health laboratory, Department of Plant Pathology, Sher-e-Bangla Agricultural University, Dhaka during the period from May, 2015 to December, 2016.

Plant materials

Different important available vegetable crops were selected for the experiment which grown in different areas of Bangladesh. The seeds of the selected vegatables were collected from the Horticulture Research Centre of Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. The crops included in the experiment were as follows.

Preparation of inoculum

Cassia tora roots were used as inocula which were collected from Agronomy field along with rhizosphere soil. The presence of AMF fungi within the root sample was confirmed using the staining procedure of Koske and Gemma (1989). Collected root samples were cut into small pieces by the help of chopper. Half of rhizosphere soils and root samples were sterilized in the autoclave at 121 ºC at 15 PSI for 15 minutes and used as base materials for control pots.

Preparation of seedling bags

The polythene bags (8" × 12", 2 kg) were perforated at the bottom portion by the perforator to remove excess water. Before preparation of substratum, soil was sterilized by formaldehyde (0.05%) and used it as base soil. Then base soil and cow dung were mixed properly with a ratio of 19:1. At first two-third portion of the seedling bags were filled with substratum. Then a layer of both inoculums i.e. root inoculum 25 g and soil inoculum 100 g were placed in each treated bag. Both 25 g roots and 100 g soil (rhizosphere) of sterilized inoculum were used in non-inoculated bags to maintain the same nutrient status between the inoculated and non-inoculated bags. The inoculum layer (both sterilized and non-sterilized) of each bag was covered with a thin soil (substratum) layer of 2 cm below the surface in which seeds were sown. Hundred polythene bags (5 × 2 × 10) were prepared and maintained for five crops under the present investigation.

Sowing of Seeds

For different crops different number of seeds was sown in the bags based on seed size. For Okra 5 seeds/bag, Tomato 30 seeds/bag, Brinjal 30 seeds/bag, Chilli 20 seeds/bag and Data 20 seeds/bag was sown. After 15 days, 5 seedlings in each bag were retained and other seedlings were removed. To avoid the chance of contamination a space of 30 cm was maintained between the inoculated and non-inoculated replications.

Data collection and analysis

Data were recorded on seedling emergence (%) (7 days after sowing, DAS, 10 DAS and 15 DAS), plant height (cm) (20 DAS, 40 DAS and 60 DAS), shoot fresh and dry weight (g) (40 DAS, 60 DAS), root fresh and dry weight (g) (40 DAS and 60 DAS), shoot and root length (cm) and disease incidence. Total nitrogen content in plants samples (shoot) were determined by micro Kjeldahl method (Bremner, 1965). Total phosphorus content in the extract was determined by Vanado-Molybdate Yellow colour methods as described by Jackson (1973). Total potassium content was determined by Atomic Absorption Spectrophotometer. Available other elements like Fe and Zn were determined following ASI method (Hunter, 1984). Nutrient uptake was calculated by using the following formula:

$$\text{Nutrient uptake} = \frac{\text{Nutrient (\%) content} \times \text{Yield}}{100}$$

Analysis of variance and comparison of mean were calculated using T-test with statistical package SPSS ver. 20 (SPSS, Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

The data pertaining to the influence of inoculation of AMF fungi on seedling emergence of Okra, Tomato, Brijnjla, Chilli and Data was presented in Table 2. The seedling emergence was calculated in three different times. With the elapse of time the seedling emergence increased in both treatments. But significantly the higher seedling emergence was found in case of inoculated plant than non-inoculated. For Okra, the percent seedling emergences increased over control in mycorrhizal treated pots was 13.79, 17.64 and 23.52, for Tomato 16.46, 45.45 and 4.47, for Brinjal 20.38, 19.75 and 51.15, for Chilli 8.65,13.67 and 17.35 and for Data 10.68, 9.58 and 7.64 at 7, 10 and 15 days after sowing, respectively. The result further showed that, the highest seedling emergence percentage was maximum in mycorrhiza treated pot at 15 days after sowing and the lowest was counted in control condition at 7days after sowing in all the vegetables under the study for the parameter of seedling emergence percentage.

Results of Table 3 showed the effect of AMF on plant height of Okra, Tomato, Brinjal, Chilli and Data. With the increase of growth period, the plant height was increased both mycorrhizal inoculated and non-inoculated plants. In both the cases, at 1st 20 days (20 DAS) and 2nd 20 days (20 to 40 DAS) after sowing the growth increment was higher than the 3rd 20 days (40 to 60 DAS) after sowing and the rate of growth was also higher than 1st and 2nd 20 days. The percent plant height increased over control in mycorrhiza inoculated pots was 6.09, 9.09 and 12.03 for Okra, 20.36, 23.89 and 19.10 for Tomato , 19.85, 9.54 and 18.23 for Brinjal, 14.90, 22.04 and 13.41 for Chilli and 25.77, 14.25 and 11.48 for Data at 20, 40 and 60 days after sowing, respectively. In case of percent growth increment for mycorrhizal inoculated plant was higher in all the vegetables under the present investigation compared to non-inoculated plants.

Influence of AMF inoculation on root growth is presented in Table 4. The root length of mycorrhizal inoculated plants in both recording period (40 and 60 days) was significantly higher in comparison to non mycorrhizal inoculated plants. It is also observed that the rate of root length increment at 40 days after sowing was higher than in 60 days after sowing in both treatments, respectively. With the increase of growth period, the root weight was increased in treated plant and more or less constant condition in control plant, but the percent root weight increased over control in mycorrhizal treated plants. At 40 DAS the maximum increased in root weight was observed in Data was 71.98% (fresh) and 52.63% (dry) which was followed by Tomato 60.00%(dry) at 40 DAS. Meanwhile, maximum root fresh weight (66.91%) and dry weight (33.33%) increased over the control was recorded in Brinjal at 60 DAS.

The data pertaining to shoot length and shoot weight (fresh and dry) of Okra, Tomato, Brinjal, Chilli and Data are presented in Table 4. Mycorrhizal inoculation significantly enhanced plant shoot length in all the vegetables under the present investigation in comparison to non-inoculated plant. It is clearly evident form the Table 5 that the percent shoot weight increased over control in all mycorrhizal inoculated in case of both fresh and dry weight. Among the mycorrhizal inoculated plants the rate of shoot weight increment in (40 DAS) was maximum (183.15% and 184.15% respectively for fresh and dry weight) in Brinjal. At 60 DAS, the highest increment of shoot weight was recorded in Brinjal which was 95.59% (fresh) and 78.25% (dry) increased over the control treatment. All other vegetables also showed positive response and increased shoot weight was observed over the control.

Table 2. Influence of Arbuscular Mycorrhizal (AMF) inoculation on seedling emergence (%) of Okra, Tomato, Brinjal, Chilli and Data

Name of the crop	Treatment	Seedling emergence (%) days after seed germination			Seedling emergence (%) increased over control		
		7 DAS	10 DAS	15 DAS	7 DAS	10 DAS	15 DAS
Okra	Non-inoculated (Control)	58.01b	68.03b	68.45b	-	-	
	Inoculated (Mycorrhiza)	66.12a	80.32a	84.33a	13.79	17.64	23.52
Tomato	Non-inoculated (Control)	56.67b	66.00b	67.00b	-	-	-
	Inoculated (Mycorrhiza)	66.00a	69.00a	70.00a	16.46	45.45	4.47
Brinjal	Non-inoculated (Control)	52.33b	55.67b	58.33b	-	-	-
	Inoculated (Mycorrhiza)	63.00a	66.67a	70.67a	20.38	19.75	51.15
Chilli	Non-inoculated (Control)	52.00b	58.50b	60.50b	-	-	-
	Inoculated (Mycorrhiza)	56.50a	66.50a	71.00a	8.65	13.67	17.35
Data	Non-inoculated (Control)	65.5b	73.00b	78.5b	-	-	-
	Inoculated (Mycorrhiza)	72.5a	80.00a	85.50a	10.68	9.58	7.64

In a column means followed by uncommon letters are significantly different at 5% level of probability by T-test.

Table 3. Influence of Arbuscular Mycorrhizal (AMF) inoculation on plant height of Okra, Tomato, Brinjal, Chilli and Data

Name of the crop	Treatment	Plant height(cm)			Plant height (%) increased over control		
		20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Okra	Non-inoculated (Control)	38.53b	75.30b	88.50b	-	-	-
	Inoculated (Mycorrhiza)	401.88a	82.15a	99.15a	6.09	9.09	12.03
Tomato	Non-inoculated (Control)	14.09b	29.29b	45.33b	-	-	-
	Inoculated (Mycorrhiza)	16.96a	36.29a	53.99a	20.36	23.89	19.10
Brinjal	Non-inoculated (Control)	8.06b	23.79b	42.66b	-	-	-
	Inoculated (Mycorrhiza)	9.66a	26.06a	50.44a	19.85	9.54	18.23
Chilli	Non-inoculated (Control)	15.63b	29.48b	41.44b	-	-	-
	Inoculated (Mycorrhiza)	17.96a	35.98a	47.00a	14.90	22.04	13.41
Data	Non-inoculated (Control)	22.00b	50.64b	57.10b	-	-	-
	Inoculated (Mycorrhiza)	27.56a	57.56a	63.66a	25.77	14.25	11.48

In a column means followed by uncommon letters are significantly different at 5% level of probability by T-test

Inoculation of pot grown vegetable plants with mycorrhizal plants resulted by the endophyte by the accompany reduction in the incidence of diseases are presented in Table 6. The damping off disease incidence was 10.78%, 8.40%, 10.05%, 10.60% and 7.60% in non-inoculated Okra, Tomato, Brinjal, Chilli and Data respectively whereas in inoculated plant it was 4.52%, 5.0%, 2.0 %, 2.50% and 5.0% respectively. The result further showed that, in case of Root rot and Leaf spot the percentage of disease incidence was almost half in inoculated plants compared to non-inoculated plants. The disease incidence was always significantly higher in non-inoculated control plant in compare to inoculated mycorrhizal Okra, Tomato, Brinjal, Chilli and Data plants.

Nutrient uptake

Inoculation of AMF responded to nutrients uptake (N, P, K, Zn and Fe) by Okra, Tomato, Brinjal, Chilli and Data are presented in Table 7. It is evident from the study that mycorrrhizal inoculation significantly enhanced nutrient uptake in shoot with comparison to non-inoculated control plants. The percent nutrient uptake of Okra increased over control for N, P, K, Zn and Fe were 22.97%, 15.0%, 50.0% 88.88% and 31.25%, respectively. In case of Tomato the percent nutrient uptake increased over control for N, P, K, Zn and Fe was 9.27%, 4.33%, 21.42%, 13.04% and 66.66%, respectively. For Brinjal the percent nutrient uptake increased over control for N, P, K, Zn and Fe were 32.92%, 26.66%, 12.67%, 57.14% and 31.50%, respectively. Again for Chilli, the percent nutrient uptake increased over control for

Table 4. Influence of Arbuscular Mycorrhizal (AMF) inoculation on root growth of Okra, Tomato, Brinjal, Chilli and Data

Name of the crop	Treatment	Root Length (cm)		Root Weight (g)				Root weight increased over control (%)			
				Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
		40 DAS	60 DAS	40 DAS	40 DAS	60 DAS	60 DAS	40 DAS	40 DAS	60 DAS	60 DAS
Okra	Non-inoculated (Control)	20.00b	36.58b	2.00b	0.30b	3.66b	0.81b	-	-	-	-
	Inoculated (Mycorrhiza)	31.16a	46.88a	2.42a	0.45a	4.16a	0.83a	21	50	13.66	2.46
Tomato	Non-inoculated (Control)	9.08b	17.88b	2.33b	0.50b	2.70b	0.80b	-	-	-	-
	Inoculated (Mycorrhiza)	10.06a	18.88a	2.41a	0.80a	4.14a	0.82a	3.43	60.00	53.33	2.5
Brinjal	Non-inoculated (Control)	16.38b	22.77b	3.28b	0.89b	2.66b	0.81b	-	-	-	-
	Inoculated (Mycorrhiza)	19.67a	28.10a	3.71a	1.08a	4.44a	1.08a	13.11	21.35	66.91	33.33
Chilli	Non-inoculated (Control)	11.58b	18.67b	1.21b	0.125b	1.33b	0.45b	-	-	-	-
	Inoculated (Mycorrhiza)	12.08a	18.77a	2.75a	0.175a	1.44a	0.60a	12.27	40	8.27	33.33
Data	Non-inoculated (Control)	17.67b	27.33b	3.57b	0.57b	4.28b	0.80b	-	-	-	-
	Inoculated (Mycorrhiza)	18.92a	27.77a	4.57a	0.87a	6.14a	0.94a	71.98	52.63	6.77	17.5

In a column means followed by uncommon letters are significantly different at 5% level of probability by T-test

Table 5. Influence of Arbuscular Mycorrhizal (AMF) inoculation on shoot growth of Okra, Tomato, Brinjal, Chilli and Data

Name of the crop	Treatment	Shoot Length (cm)		Shoot Weight (g)				Shoot weight increased over control (%)			
				Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
		40 DAS	60 DAS	40 DAS	40 DAS	60 DAS	60 DAS	40 DAS	40 DAS	60 DAS	60 DAS
Okra	Non-inoculated (Control)	75.30b	88.50b	25.50b	4.05b	27.00b	4.82b	-	-	-	-
	Inoculated (Mycorrhiza)	82.15a	99.15a	30.25a	5.00a	31.66a	5.95a	18.62	3.73	17.25	46.91
Tomato	Non-inoculated (Control)	29.29b	45.33b	9.33b	1.81b	9.60b	1.85b	-	-	-	-
	Inoculated (Mycorrhiza)	36.29a	53.99a	11.33a	2.52a	11.60a	2.61a	21.43	39.22	20.83	41.08
Brinjal	Non-inoculated (Control)	23.79b	42.66b	6.71b	1.37b	9.77b	2.25b	-	-	-	-
	Inoculated (Mycorrhiza)	26.06a	50.44a	19.00a	3.90a	19.11a	4.01	183.15	184.15	95.59	78.25
Chilli	Non-inoculated (Control)	29.48b	41.44b	3.12b	0.47b	6.33b	1.62b				
	Inoculated (Mycorrhiza)	35.98a	47.00a	6.75a	1.17a	8.00a	1.70a	116.34	148.93	26.38	4.93
Data	Non-inoculated (Control)	50.64b	57.10b	15.10b	1.62b	24.17b	4.28b	-	-	-	-
	Inoculated (Mycorrhiza)	57.86a	63.66a	31.85a	3.32a	33.85a	4.42a	110.9	64.77	40.04	3.27

In a column means followed by uncommon letters are significantly different at 5% level of probability by T-test

Table 6. Influence of Arbuscular Mycorrhizal (AMF) inoculation on disease incidence of Okra, Tomato, Brinjal, Chilli and Data

Name of the crop	Treatment	Infected plant (%)		
		Root rot/Foot rot	Damping off	Leaf spot
Okra	Non-inoculated (Control)	6.48a	10.78a	8.67a
	Inoculated (Mycorrhiza)	3.24b	4.52b	4.23b
Tomato	Non-inoculated (Control)	6.57a	8.40a	7.98a
	Inoculated (Mycorrhiza)	2.21b	5.00b	2.34b
Brinjal	Non-inoculated (Control)	5.70a	10.05a	7.2a
	Inoculated (Mycorrhiza)	2.50b	2.00b	3.6b
Chilli	Non-inoculated (Control)	4.98a	10.60a	6.4a
	Inoculated (Mycorrhiza)	2.80b	2.50b	3.6b
Data	Non-inoculated (Control)	6.00a	7.60a	5.42a
	Inoculated (Mycorrhiza)	4.33b	5.00b	3.00b

In a column means followed by uncommon letters are significantly different at 5% level of probability by T-test

N, P, K, Zn and Fe were 12%, 3.33%, 7.40%, 35.71% and 64.70% respectively. Meanwhile the percent nutrient uptake of Data increased over control for N, P, K, Zn and Fe were 5.69%, 20%, 22.58%, 190.90% and 112.50% respectively. The result further showed that Zn and Fe uptake percentage was comparatively higher than other nutrient uptake in inoculated plants compared to non-inoculated control plants. Meanwhile, the highest N and P uptake was recorded in Brinjal.

Discussion

Vegetables grown in organic production systems are often exposed to nutrient deficiency resulting from low amounts of nutrients in the soil or to the poor solubility of nutrients in soil solution. The symbiotic association of roots with AM fungi is a widespread strategy by which plants facilitate the acquisition of mineral elements from the soil. This association basically happens in two phases: extraradical, in which hyphal contact with the root cortex of the host plant occurs; and intra-radical, with the development of intra-radical hyphae and specialized structures called arbuscules (finely branched hyphae involved in nutrient exchange). (Peterson et al. 2004; Smith and Read 2008; Giovannetti et al. 2010). From the present study all growth parameters under consideration like seedling emergence, height of the plants, length of roots, fresh and dry weight of plants were recorded to be significantly higher in AMF treated plants than the control set. This might be due to the fact that AMF increases nutrient solubility present in soil and enhance nutrient uptake which facilitated the increment in growth parameters. The present findings are in agreement with Rouphael et al. (2010) who reported that AMF can also enhance P availability under nutrient deficiency/availability typical of organic farming systems. Rouphael et al. 2015 further stated that the basis of the soil P availability improvement has been associated to the developed network of the external hyphae capable of extending the surface area for nutrient uptake and to the production of phosphatases and excretions of organic substances able to solubilize P. Moreover, mycorrhizal fungi can indirectly increase nutrient availability in the soil through the improvement of soil aggregate stability (resulting from the soil particle binding agent 'glomalin' released by AMF) which increases root growth and activity (Wu et al. 2011). Mycorrhizal fungi can improve absorption of phosphorus (Jiang, W et al. 2013), potassium and magnesium (Liu A. et al. 2002). Our results are also supported by research of Singh et al. (2004), reported that nutrient uptake of mycorrhizal plants was higher when compared with non-mycorrhizal one. From the present study it is evident that the root and shoot length and biomass (both fresh and dry) has increased significantly higher in AMF inoculated plants compared to the non-inoculated control plants. Several studies reported that endophytic fungi such as AMF can promote plant rooting by stimulation of auxin production in mycorrhized roots or release of auxin-like compounds from hyphae (Ruzzi and Aroca, 2015; Colla et al. 2015). Giri et al. (2005) reported that root and shoot dry weights were higher in mycorrhizal than non-mycorrhizal plants and our findings is in agreement with their findings. Besides increasing nutrient uptake, arbuscular mycorrhizal fungi can enhance nutrient assimilation (formation of organic nitrogen compounds from inorganic nitrogen) as reported by Caravaca et al. (2007). The nutrient uptake (N, P, K, Zn and Fe) was highly influenced by AM inoculation. The finding from Douds and Miller (1999) was that the association of AM fungi increases uptake of immobile nutrients especially phosphorus and micronutrients. Other studies have also confirmed the absorption of Zn (Bürkert and Robson 1994; Jansa et al. 2003), Allen and Shachar-Hill 2009) and Fe (Caris et al. 1998) via

Table 7. Influence of Arbuscular Mycorrhizal (AMF) inoculation on nutrient uptake of Okra, Tomato, Brinjal, Chilli and Data

Name of the crop	Treatment	Nutrient uptake by shoot (%)				
		N	P	K	Zn	Fe
Okra	Non-inoculated (Control)	0.74b	0.40b	1.60b	0.009b	0.016b
	Inoculated (Mycorrhiza)	0.91a	0.46a	2.40a	0.017a	0.021a
	% Increased over control	22.97	15.00	50.00	88.88	31.25
Tomato	Non-inoculated (Control)	1.51b	0.46b	2.80b	0.023b	0.003b
	Inoculated (Mycorrhiza)	1.65a	0.48a	3.40a	0.026a	0.005a
	% Increased over control	9.27	4.33	21.42	13.04	66.66
Brinjal	Non-inoculated (Control)	0.82b	0.30b	2.13b	0.007b	0.019b
	Inoculated (Mycorrhiza)	1.09a	0.38a	2.40a	0.011a	0.025a
	% Increased over control	32.92	26.66	12.67	57.14	31.50
Chilli	Non-inoculated (Control)	1.75b	0.30b	2.70b	0.014b	0.017b
	Inoculated (Mycorrhiza)	1.96a	0.31a	2.90a	0.019a	0.028a
	% Increased over control	12	3.33	7.40	35.71	64.70
Data	Non-inoculated (Control)	1.23b	0.40b	3.10b	0.011b	0.016b
	Inoculated (Mycorrhiza)	1.30a	0.48a	3.80a	0.032a	0.034a
	% Increased over control	5.69	20	22.58	190.90	112.50

In a column means followed by uncommon letters are significantly different at 5% level of probability by T-test

AM fungi. Therefore, mycorrhizal association is found to be beneficial to the plants in terms of better nutrient uptake and better water potential which lead the plants to become healthier and productive than non-mycorrhizal plants. In addition to these benefits, AM fungi improve plant–water relations, increase resistance or tolerance to biotic and abiotic stresses and reduce disease incidence for better plant stand (Smith and Read 2008). The present study indicated that mycorrhizal inoculation increased the growth and nutrient uptake of all the selected vegetable crops inoculated under control conditions. However, among the selected vegetables; Brinjal showed the best positive response in terms of growth and nutrient uptake. Therefore, this technology might be useful for growth of vegetable crops in sustainable production system especially for Brinjal.

CONCLUSIONS

Mycorrhizal inoculation in plant root improves mineral nutrients solubility, uptake, reduce disease incidence and promote plant growth. Results from the present study depicts that macro nutrients concentration and uptake as well as micro nutrients concentration and uptake is higher in mycorrhizal inoculated plant than non-inoculated plant which may be an efficient strategy to utilize environment friendly bio-fertilizer instead of chemical fertilizer. Therefore, it may be concluded that the fungi offer an environmentally sound biological alternative to chemical fertilizer and pesticides for maintaining plant quality and productivity in sustainable agriculture. In addition, more research is need for the development of techniques that aim to understand the mechanisms that control AMF formation may contribute towards the effective large-scale application of AM fungi in sustainable agriculture.

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