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FULL-LENGTH RESEARCH ARTICLE

Identification of Dominant Arbuscular Mycorrhizal Fungi in Different Rice Ecosystems

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Abstract Rice is a staple food in Goa. It is cultivated in three different ecosystems, viz, lowland (*khazan*), midland (*ker*) and upland (*morod*). The present investigation was carried out for two consecutive years, i.e., 2015 and 2016 to study the diversity of arbuscular mycorrhiza (AM) and identify the dominant species in the three different rice ecosystems of Goa. The native dominant AM species identified from the study can be further employed for developing AM inocula. The study revealed 17 AM fungal species recorded from the three ecosystems and belonged to six genera, viz., *Acaulospora* (9), *Rhizoglomus* (1), *Entrophospora* (1), *Claroideoglomus* (2), *Funneliformis* (1) and *Gigaspora* (3). There was dominance of different genera in different ecosystems. The genus *Acaulospora* was abundant in lowlands, genus *Gigaspora* in midlands and the genus *Claroideoglomus* in upland fields. This study suggests the possibility of using inocula of the dominant AM species in the respective ecosystems for increased plant growth and yield.

Keywords AM fungi · Diversity · Dominance · Inocula

Introduction

One of the important crops grown in many tropical countries of the world is rice (*Oryza sativa* L.). It is grown in different ecosystems defined on the basis of hydrology, roughly classified as irrigated, rainfed lowland, upland and flood prone. Approximately, half of the world rice area is irrigated and of the remainder is distributed among rainfed lowland (25%), uplands (13%) and flood prone (9%) [11, 12, 15]. The degree of flooding is determined by a number of variables such as rainfall pattern and intensity, topography, soil properties and drainage system [16].

Rice is the staple food of Goa. The crop is cultivated in three different topographical situations, i.e., upland (*morod*), midland (*ker*) and lowland (*khazans*) mainly as wet season (*kharif*) crop from June to October. Rice cultivation in uplands is 16.4% of the total rice area in the state. The growing period is 115–120 days. Fields are prepared by plowing early in the season followed by leveling so that the field is ready for sowing before the regular onset of monsoon. Pre-germinated seeds are broadcasted, or plantlets are transplanted by planting uniformly in lines spaced by 20 cm. Broadcasting and transplanting are carried out with a thin film of water. Rice crop cultivated in midland is 32% of the total rice area in the state. The crop grown in this ecosystem has relatively longer growing period (130–135 days). Seedlings are raised in wet or dry nurseries after germination. The seedlings are ready for transplanting after 21–24 days. Three to four seedlings are planted per hill at a distance of 20 × 10 cm. Seedlings are transplanted in fields that are plowed and leveled at the first shower. Rice cultivation in the lowland occupies an area of 32% of the rice area in the state, with varieties having growth duration of 105–115 days. Fields are plowed in the summer. Seeds are either broadcasted or transplanted by raising a nursery. However, in the lowland, it is essential to sow at regular onset of monsoon after ensuring flushing of salts from the fields [24].

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Mycorrhiza is a mutualistic association between fungi and plant roots. The fungus enters into the cortex of the roots to obtain carbon from the host plant, and in return it assists the plants with the uptake of phosphorus (P) and other nutrients from the soil [2]. Besides, other functions attributed to AM fungi include production of plant growth hormones, protection of host from pathogens and salinity tolerance [4, 5].

Rice plants readily form AM association in upland [23] and midland [48] condition, but under submerged condition colonization is rare due to the anoxic environment [13]. However, Barea [3] concluded that AM fungi are obligate aerobes in nature, but can survive in waterlogged condition. Lower rate of AM fungal colonization was observed in rice roots in wet as compared to dry condition, and the rate of AM fungal colonization decreased during rice growth as observed by Solaiman and Hirata [44]. The increasing awareness of occurrence of AM fungi in wetland ecosystem [14, 26, 29, 51, 53] leads to the conclusion that soil conditions determine the mycorrhizal status of the host. Miller [27] and Wang et al. [51] found a decrease in the degree of AM fungal colonization with flooding along wetland gradient. But the presence of AM fungi in wetland ecosystem is closely related to the well-developed aerenchyma in wetland plant roots [19, 26, 51] that allows AM fungi to obtain atmospheric oxygen [32].

In the recent past, attempts have been made to obtain suitable formulation for AM fungal inocula and appropriate ways for their application in the field [8]. The development of inocula based on AM fungi has to take into account the indigenous AM fungal population. Hence, the aim of the present work was to study the distribution of native AM fungal community in different ecologies in order to formulate AM inocula types for different ecosystems.

Materials and Methods

Collection Sites

Rhizosphere soil samples (Table 1) from three rice varieties, viz, Jyoti, Khonchri and Jaya were collected from lowland, midland and upland during the vegetative, flowering and harvesting stages for two consecutive years, viz, 2015 and 2016. In all, 81 rhizosphere soil samples were collected and brought to the laboratory for further processing.

Collection of Samples

Three healthy plants were selected from three different positions in the field. Soil and root samples were taken from a depth of 0–25 cm, in polyethylene bags and brought to the laboratory. The roots were separated from adhering soil by washing gently under tap water and were used for estimation of AM colonization. The rhizosphere soil of the three healthy plants from each site at each growth stage was pooled to form composite sample. The composite soil samples were then divided into three parts, for (i) isolation, enumeration and identification of AM spores, (ii) preparing trap cultures and (iii) soil analysis.

Soil Analysis

Soil pH was measured in 1:1 water solution suspension using a pH meter (LI 120 Elico, India). Electrical conductivity (EC) was measured using conductivity meter (CM 180 Elico, India). Walkley and Black [52] rapid titration method was used to estimate organic carbon content. Nitrogen was assessed by micro-Kjeldahl method [17]. Available P was estimated using Bray and Kurtz method [6]. Potassium (K) was estimated by ammonium acetate method [9]. Zinc, iron, manganese and copper were quantified by DTPA-$CaCl_2$-TEA method from Lindsay and Norvell [20] using atomic absorption spectrophotometer

Table 1 Rice varieties and geographical location of the study sites

Ecosystem	Site	Rice variety	Geographical coordinates		
			Latitude	Longitude	Altitude (m above msl)
Lowland (*Khazan*)	Sikeri	Jyoti, Khonchri	15° 35′ 18″ N	73° 53′ 20″ E	7
	Tuem	Jaya	15° 30′ 22″ N	73° 48′ 12″ E	3
Midland (*Ker*)	Saligao	Jyoti Khonchri	15° 33′ 07″ N	73° 47′ 01″ E	29
	Velim	Jaya	15° 09′ 39″ N	73° 58′ 45″ E	21
Upland (*Morod*)	Morpilla	Jyoti	15° 06′ 53″ N	73° 59′ 54″ E	378
	Quitolla	Khonchri, Jaya	15° 07′ 58″ N	73° 57′ 36″ E	204

msl mean sea level

(AAS-EC Element AS AAS4139). Chemical analyses of the soil samples were carried out at Soil Science Laboratory, ICAR-CCARI, Old Goa.

Estimation of AM Fungal Root Colonization

The root samples of three different rice varieties were collected at three different growth stages from three different ecosystems. Roots were washed thoroughly in tap water, cut into 1-cm fragments and stained with Trypan blue following the method described by Phillip and Hayman [32]. Fifty stained roots were examined for AM fungal structures. Percentage of root colonization was determined by root slide method [34].

Isolation and Identification of AM Spores

Spores were isolated from rhizosphere soil samples using wet sieving and decanting method [7]. Intact and crushed spores were mounted in polyvinyl lacto-glycerol and examined under an Olympus research compound microscope (100×–1000×). Morphological identification of the spores was carried out by using bibliographies [1, 36], and the culture database established by INVAM.

Diversity Studies and Statistical Analysis

Mycorrhizal Diversity for each ecosystem was studied separately by calculating:

A. Frequency of occurrence (%) = $\frac{\text{Number of soil samples containing spores of particular AM species}}{\text{Total number of soil samples screened}} \times 100$ [4]

B. Relative abundance (%) = $\frac{\text{Number of spores of particular AM species}}{\text{Total spore number of all the AM Species}} \times 100$ [4]

C. Species richness (SR) is the number of AM fungal species recovered from each site per sample collection

D. Simpson's Index of Diversity: $1 - D$ [40]

$$D = 1 - \Sigma(P_i)^2$$

$$P_i = n_i/N$$

n_i—the relative abundance of the species calculated as the proportion of individuals of a given species to the total number of individuals in a community N.

E. Shannon diversity index (H) by Shannon and Wiener [42] is commonly used to characterize species diversity in a community, accounting for both abundance and evenness of the species present.

$$H = -\Sigma(P_i In(P_i))^2.$$

F. Significant difference between colonization and spore density for each variety at the different growth stages were carried out by ANOVA and seperated using Tukey using SPSS Statistics 20.

G. To examine the relationship between the relative abundance of AM fungi and the physicochemical properties of soil at the different ecosystems, Canonical correspondence analysis (CCA) was carried out using Multivariate Statistical Package (MVSP) program version 3.1.

Results and Discussion

Soil Physicochemical Analyses

Goa is one of the smallest states of India and accounts for about one percent of the total area of the country. It has a 101 km long coast line. Its length from north to south is 105 km and from west to east is 60 km. It is part of the Konkan region which is an escarpment rising up to the Western Ghats. Most of Goa's soils is made up of laterite rock. Along the river banks, the soil is mostly alluvial and loamy. The soil is rich in minerals and humus and hence conducive to plantation. The results of the physicochemical analyses of the soil of the three ecosystems (Table 1) studied are depicted in Tables 2 and 3. The soils of the three ecosystems were acidic with its average pH ranging from 5.42 to 5.62. However, there was a significant difference in organic carbon (OC), nitrogen (N), manganese (Mn) and potassium (K) (Table 4). OC, N and Mn were maximum in the uplands and the least in the midland. This variation in soil could be due to fertilizer application [25], vegetation, cropping history, temperature and type of ecosystem.

AM Fungal Root Colonization

AM fungal root colonization was recorded in all the three rice varieties for all the growth stages in both years in each rice growing ecosystem. In all the three varieties, the different ecosystems and growth stages had a significant effect on AM colonization for both years of study.

In all the three rice varieties (Fig. 1a–c) studied, i.e., Jyoti, Khonchri and Jaya, maximum colonization was observed in upland and midland during the flowering stage and minimum colonization in the lowlands at the vegetative stage for both years. It has been documented that flooding in the lowland and high-input cropping systems depresses AM fungal colonization in rice roots [22, 26]. The extent of root colonization is known to vary with soil and climatic conditions [33].

Table 2 Physicochemical properties of soil (2015)

Land type and growth stage	pH	EC (dS m^{-})	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Iron (ppm)	Manganese (ppm)	Copper (ppm)	Zinc (ppm)
LV	5.93	0.06	1.44	400.18	28.9	208.9	34.49	20.6	2.74	1.46
LF	5.8	0.13	1.01	298.36	17.14	153.55	28.12	8.38	1.01	2.21
LH	5.7	0.12	1.3	356.11	125.83	162.06	38.5	18.87	2.76	2.57
MV	6.05	0.18	0.65	253.96	63.38	95.93	31.65	14.57	2.3	2.07
MF	5.78	0.1	0.98	152.1	117	117.55	40.86	14.75	2.15	2.76
MH	5.91	0.18	0.62	212.2	210.28	87.31	35.35	6.01	1.03	0.91
UV	6.39	0.17	3.64	1115.93	85.17	205.19	38.32	23.27	1.69	1.12
UF	5.95	0.06	4.53	1000.67	55.37	155.66	37.85	20.48	1.36	0.68
UH	5.84	0.22	4.46	864.78	69.08	117.33	36.67	22.98	1.66	0.58

Data presented is mean of six readings at each growth stage *LV* lowland vegetative stage, *LF* lowland flowering stage, *LH* lowland harvesting, *MV* midland vegetative stage, *MF* midland flowering stage, *MH* midland harvesting, *UV* upland vegetative stage, *UF* upland flowering stage, *UH* upland harvesting

Table 3 Physicochemical properties of soil (2016)

Land type and growth stage	pH	EC (dS m^{-1})	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Iron (ppm)	Manganese (ppm)	Copper (ppm)	Zinc (ppm)
LV	4.34	0.29	1.22	245.77	34.27	200.31	50.36	5.71	0.29	1.57
LF	5.17	0.46	1.02	260.18	36.3	227.93	36.34	8.26	0.29	1.18
LH	5.55	0.68	1.76	210.63	39.23	380.7	26.66	14.3	0.33	0.86
MV	5.55	0.09	0.92	127.52	38.45	109.84	20.4	4.6	0.21	6.44
MF	5.07	0.21	1.59	294.44	31.76	95.62	19.04	7.62	0.08	0.45
MH	4.96	0.38	0.59	165.16	32.23	86.39	32.83	2.34	0.12	0.84
UV	5.62	0.09	1.6	499.74	20.36	252.52	37.76	17.71	0.16	0.81
UF	4.71	0.25	2.32	435.57	26.03	172.22	28.11	7.21	0.14	1.12
UH	5.19	0.08	2.59	369.56	40.04	76.84	39.97	13.73	0.21	0.51

Data presented is mean of six readings at each growth stage; *LV* lowland vegetative stage, *LF* lowland flowering stage, *LH* lowland harvesting, *MV* midland vegetative stage, *MF* midland flowering stage, *MH* midland harvesting, *UV* upland vegetative stage, *UF* upland flowering stage, *UH* upland harvesting

AM Fungal Spore Density

In the present study, average spore density in rhizosphere soil samples in various growth stages and different rice growing ecosystems was estimated. The present study revealed that phenology and sampling site had significant effect on spore density. AM fungal spore density increased at harvesting stage compared to the vegetative and flowering stage irrespective of rice variety and ecosystem (Fig. 2a–c). Similar results were observed by Janos [18] and Redhead [35]. According to Bentivenga and Hetrick [5], AM fungal sporulation is stimulated as the plant nutrient requirement reduces. The rise in AM spore population at harvest stage may be due to fungal resource mobilization from the senescing roots [10, 28, 47]. Compared to the midland and upland, the spore density was low in lowlands for both the years. This may be because of the anaerobic soil conditions caused due to flooding [30] and nutrients availability [2]. However, Miller and Beaver [27] identified two mechanisms by which AM fungi could survive in anoxic conditions. Firstly, some AM species may require less oxygen, and secondly, the AM fungus could be concentrated near the plant roots, obtaining oxygen directly from the root or as oxygen diffuses from the root into the rhizosphere.

The role of soil nutrient concentration on colonization ability by AM fungi and spore density was investigated during the study. There was no significant correlation between root colonization percentage and sporedensity. AM fungal colonization depends on soil moisture and P availability [38, 49, 50] and physiological growth rate and turnover of plant root [21]. However, a significant correlation of spore density with nitrogen ($r = 0.457$), phosphorus ($r = 0.504$) and OC ($r = 0.547$) was observed at

Table 4 Average physicochemical properties of soil

Physicochemical properties of soil	Ecosystem		
	Lowland	Midland	Upland
pH	$5.41^{a} \pm 0.24$	$5.55^{a} \pm 0.18$	$5.61^{a} \pm 0.24$
EC (dS m^{-1})	$0.29^{a} \pm 0.09$	$0.19^{a} \pm 0.04$	$0.14^{a} \pm 0.03$
Organic carbon (%)	$1.29^{b} \pm 0.11$	$0.89^{b} \pm 0.15$	$3.19^{a} \pm 0.49$
Nitrogen (kg ha^{-1})	$295.05^{b} \pm 29.49$	$200.89^{b} \pm 26.29$	$714.37^{a} \pm 130.19$
Phosphorus (kg ha^{-1})	$46.94^{a} \pm 16.09$	$82.18^{a} \pm 28.82$	$49.34^{a} \pm 10.29$
Potassium (kg ha^{-1})	$222.24^{a} \pm 33.73$	$98.77^{b} \pm 5.09$	$163.29^{ab} \pm 25.45$
Iron (ppm)	$35.74^{a} \pm 3.48$	$30.02^{a} \pm 3.50$	$34.44^{a} \pm 1.72$
Manganese (ppm)	$12.68^{ab} \pm 2.51$	$8.31^{b} \pm 2.12$	$17.56^{a} \pm 2.53$
Copper (ppm)	$1.23^{a} \pm 0.49$	$0.98^{a} \pm 0.41$	$0.87^{a} \pm 0.31$
Zinc (ppm)	$1.64^{a} \pm 0.26$	$2.24^{a} \pm 0.91$	$0.80^{a} \pm 0.10$

Data presented is mean of nine readings at each ecosystem, ± indicates S.E.; for each ecosystem, values in the row affected by the same letter are not significantly different at $P \leq 0.05$ level of probability

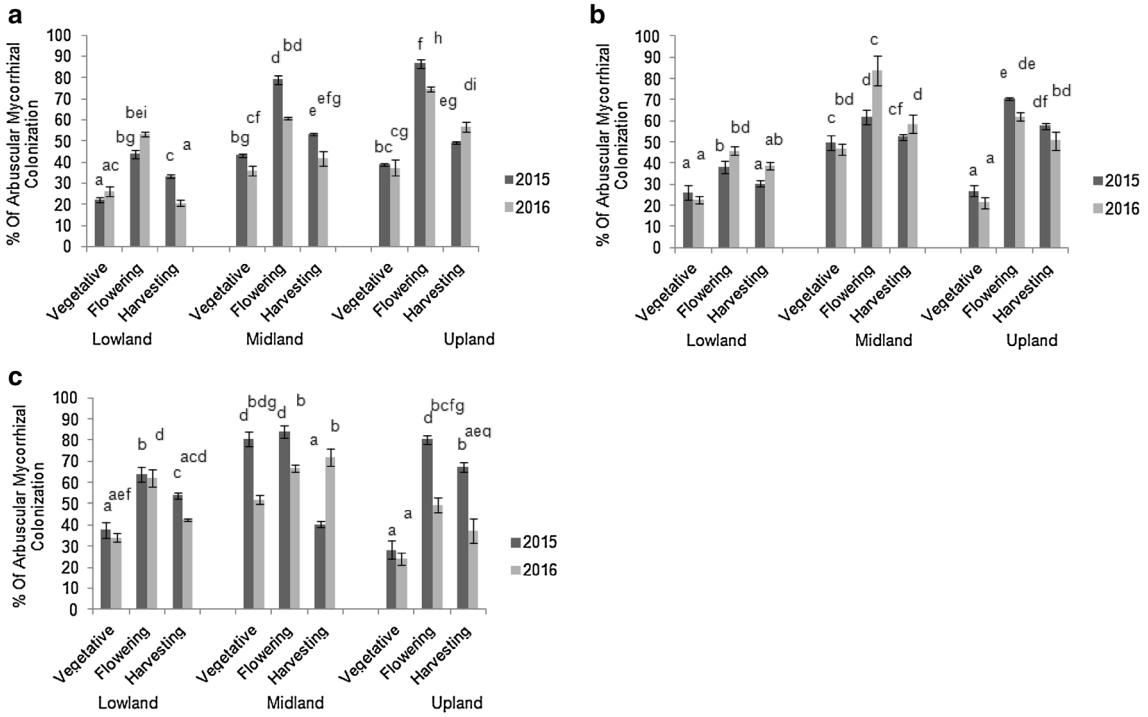

Fig. 1 Effect of plant phenology on AM fungal root colonization in *O. sativa* where **a**-var. Jyoti; **b**-var. Khonchri and **c**-var. Jaya. Data presented is the mean of three readings at each growth phase; different letters within the variety of study indicate significant differences at $P \leq 0.05$; Bars represents SE

$P < 0.05$ level. It is known that seasonality edaphic factors, age of host plant and dormancy can also contribute to variation in spore density [54].

AM Fungal Diversity, Richness, Abundance and Distribution

A total of 17 AM fungal species belonging to six genera, viz., *Acaulospora* (9), *Rhizoglomus* (1), *Entrophospora* (1), *Claroideoglomus* (2) *Funneliformis* (1) and *Gigaspora* (3) with species number given in parenthesis were recorded from different ecosystems. The study revealed that

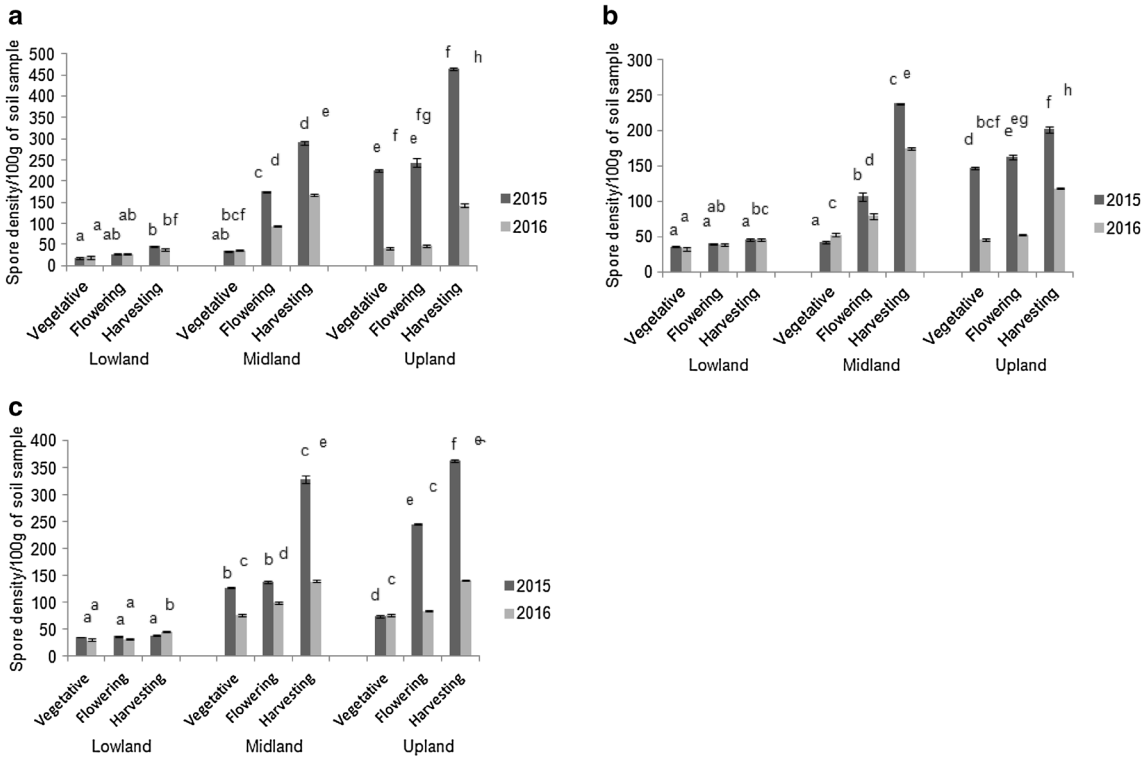

Fig. 2 Effect of Plant phenology on AM fungal spore density in *O. sativa* where **a**-var. Jyoti; **b**-var. Khonchri and **c**-var. Jaya. Data presented is the mean of three readings at each growth phase; different letters within the variety of study indicate significant differences at $P \leq 0.05$; Bars represents S.E

Acaulospora was the most dominant genus in the studied ecosystems. Maximum species richness was recorded in lowland (10) for both years with species number given in parenthesis.

In lowlands, *Acaulospora scrobiculata*, *A. delicata, A. dilatata, A. laevis, A. tuberculata, A. myriocarpa*, *A. soloidea*, *Funneliformis mosseae*, *Rhizoglomus fasciculatum* and *Entrophospora nevadensis* were recorded in both years. Frequency of occurrence was maximum for *A. scrobiculata* and *R. fasciculatum* as they were recorded in all the growth phases for both years (Table 5). Genus *Acaulospora* showed maximum relative abundance for both years (Fig. 3). Species of *Acaulospora* are identified mainly in low-input farming system, forest and grassland soils. They are considered as facultative symbionts adapted to a wide array of soils and host species, appearing in soils of widely different pH and nutrient availability [39, 43, 46].

In midlands, *Acaulospora scrobiculata, A. bireticulata, A. rehmii, A. dilatata Gigaspora ramisporophora, Claroideoglomus claroideum* and *Entrophospora nevadensis* were recorded in 2015. In 2016, three additional species, viz., *Funneliformis mosseae, Gigaspora albida* and *G. decipiens* were recorded. Frequency of occurrence was maximum in *A. scrobiculata and G. ramisporophora* (Table 6). Genus *Gigaspora* showed maximum relative abundance in both the years (Fig. 3). Similar observations were reported by Toppo et al. [48], suggesting Genus *Gigaspora* may be better adapted to semi-aerobic to anaerobic soils.

In the uplands, *A. scrobiculata, A. bireticulata, Claroideoglomus claroideum, C. etunicatum* and *Entrophospora nevadensis* were recorded in both years. Frequency of occurrence was maximum for *C. claroideum* (Table 7) and *E. nevadensis.* Genus *Claroideoglomus* showed maximum relative abundance for both years (Fig. 3). Predominance of *Glomus* in aerobic soil condition of uplands was observed by Maiti et al, [23] and Toppo et al, [48]. The dominance of *Glomus* in the uplands might be related to their competitive interaction and adaptability to aerobic conditions allowing them to establish better than others [41, 45].

The potential correlation of AM fungal abundance and physicochemical properties of the soil in the different ecosystems was performed by Canonical correspondence analysis (CCA). In the CCA plot, the length of the arrows illustrated the relative importance affecting the community, while the angle between the variables indicates the degree to which factors are correlated. The resulting ordination is presented in Fig. 4, and the Eigen values of the first and

Table 5 Distribution of AM fungi at Lowlands

Sr. No.	AM species	2015			2016			Frequency of occurrence (%)
		Vegetative	Flowering	Harvesting	Vegetative	Flowering	Harvesting	
1	*Acaulospora scrobiculata*	+	+	+	+	+	+	100
2	*Acaulospora delicata*	−	+	+	−	+	+	66.66
3	*Acaulospora dilatata*	−	−	+	−	−	+	33.33
4	*Acaulospora laevis*	–	−	+	−	−	+	33.33
5	*Acaulospora tuberculata*	−	−	+	−	−	+	33.33
6	*Acaulospora myriocarpa*	+	−	+	+	−	−	50.00
7	*Acaulospora soloidea*	−	+	+	−	−	+	50.00
8	*Funneliformis mosseae.*	+	+	−	+	+	+	83.33
9	*Rhizoglomus fasciculatum*	+	+	+	+	+	+	100
10	*Entrophospora nevadensis*	−	+	+	−	+	+	66.66
Species richness of AM fungi		4	6	9	4	5	9	−

+ Presence of AM fungi; − absence of AM fungi

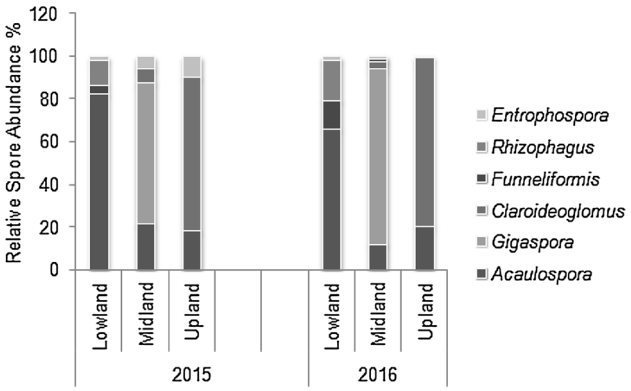

Fig. 3 Genus-wise relative abundance distribution of AM genera cultivated in different ecological sites for the year 2015 and 2016

second axes were 0.583 and 0.471, respectively. The cumulative percentage variance of genera data showed 34.83% and 62.95% of variability on the first and second axes, respectively. Genus *Claroideoglomus* shows a high relative abundance % in the uplands which is closely related to the high content of OC, N, Mn and Fe content in the soil. Midlands show a high relative abundance % of the genus *Gigaspora*, and it is strongly related to the high content of Zn and low content of P. In the lowlands, the genus *Acaulospora* shows a high relative abundance percentage which shows tolerance to EC fluctuations, Cu and K content.

Diversity was calculated by using Shannon's diversity index (H) and Simpson's index of diversity (D) at the

Table 6 Distribution of AM fungi at midlands

Sr. No.	AM species	2015			2016			Frequency of occurrence (%)
		Vegetative	Flowering	Harvesting	Vegetative	Flowering	Harvesting	
1	*Acaulospora scrobiculata*	+	+	+	+	+	+	100
2	*Acaulospora bireticulata*	−	−	+	−	−	+	33.33
3	*Acaulospora dilatata*	+	−	−	−	−	−	16.66
4	*Acaulospora rehmii*	+	−	+	+	−	+	66.66
5	*Gigaspora ramisporophora*	+	+	+	+	+	+	100
6	*Gigaspora albida*	−	−	−	−	+	+	33.33
7	*Gigaspora decipiens*	−	−	−	−	+	+	33.33
8	*Claroideoglomus claroideum*	−	−	+	−	−	+	33.33
9	*Funneliformis mosseae.*	−	−	−	+	−	−	16.66
10	*Entrophospora nevadensis*	−	+	+	−	+	+	66.66
Species richness of AM fungi		4	3	6	4	5	8	−

+ Presence of AM fungi; − absence of AM fungi

Table 7 Distribution of AM fungi at uplands

Sr. No.	AM species	2015			2016			Frequency of occurrence %
		Vegetative	Flowering	Harvesting	Vegetative	Flowering	Harvesting	
1	*Acaulospora scrobiculata*	+	+	−	+	+	−	66.66
2	*Acaulospora bireticulata*	−	−	+	−	−	+	33.33
3	*Claroideoglomus claroideum*	+	+	+	+	+	+	100
4	*Claroideoglomus etunicatum*	−	+	+	−	+	+	66.66
5	*Entrophospora nevadensis*	+	+	+	+	+	+	100
Species Richness of AM Fungi		3	4	4	3	4	4	−

+ Presence of AM fungi; − absence of AM fungi

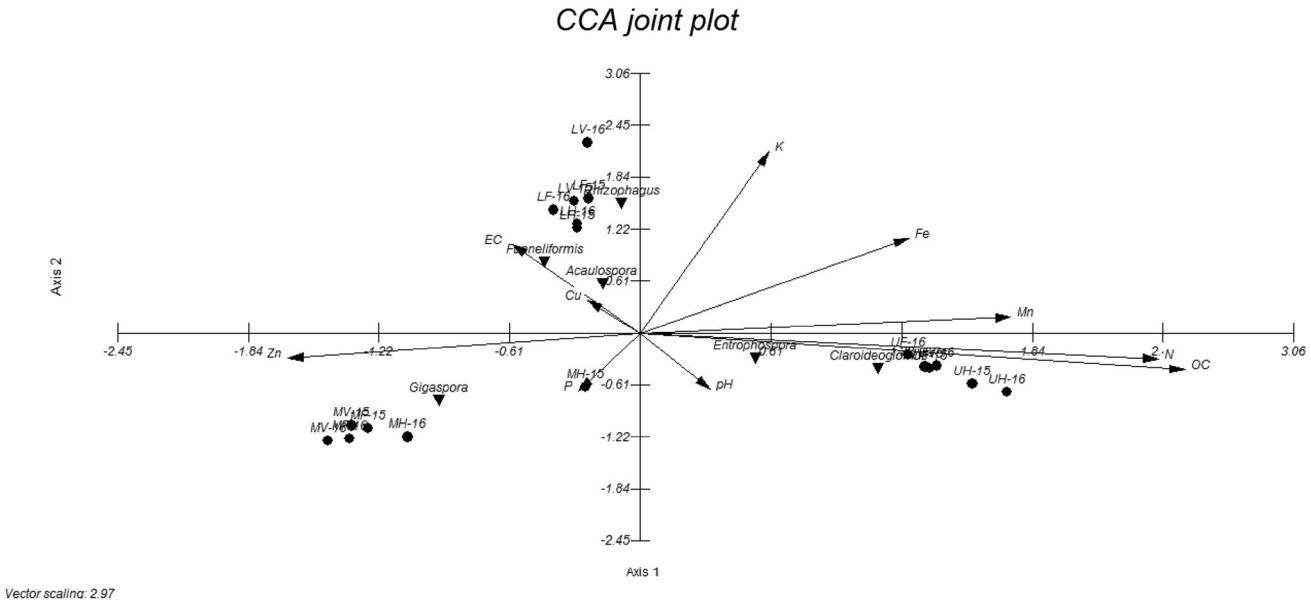

Fig. 4 CCA of soil physicochemical properties and relative spore abundance % of different AM genera in different ecosystems. Diagram of CCA of soil properties pH, EC, OC, N, P, K, S, Fe, Mn, Cu, Zn and Genus-wise relative abundance distribution of AM genera at the different ecosystems: *LV* Lowland vegetative stage, *LF* lowland flowering stage, *LH* lowland harvesting, *MV* midland vegetative stage, *MF* midland flowering stage, *MH* midland harvesting, *UV* upland vegetative stage, *UF* upland flowering stage, *UH* upland harvesting

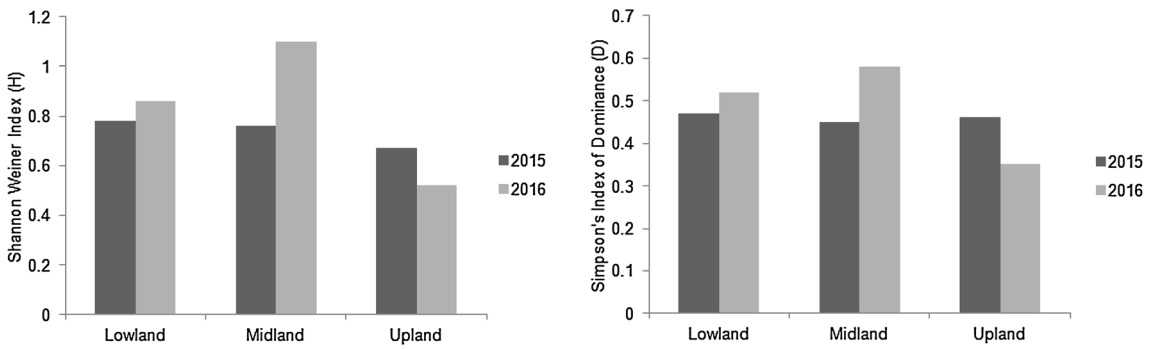

Fig. 5 AM fungal species density in *O. sativa*. Data presented is the mean of nine readings at each ecosystem

species level for the three ecosystems (Fig. 5). Maximum AM diversity was recorded in lowlands in 2015, midland in 2016 and minimum in uplands for both the years. Some AM fungi have high tolerance to soil hypoxia or even anoxia [51]. High diversity may be important for buffering an ecosystem against disturbances [49]. Occurrence of maximum number of species results in higher index of diversity. Maximum diversity observed in the lowlands indicated shared dominance of many AM fungal genera. The lowest diversity observed in uplands indicates dominance of a few genera.

Conclusions

All the rice fields in the different ecosystems are conventionally managed with each ecosystem having its own cultivation practice. The difference in ecosystem, ecology and cultural practices can cause changes in the suitability for growth of AM fungi. Hence, AM fungi tolerant to conditions in a particular ecosystem proliferate. In the present study, dominance of different genera in different ecosystems, viz, genus *Acaulospora* dominant in lowlands, *Gigaspora* in midlands and *Claroideoglomus* in uplands was observed. As AM fungal colonization from the native soil is better in efficacy [31], cost effectiveness and adaptation with lesser negative ecological consequences in terms of invasive species [37], they can be employed as inocula for different ecosystems. Our study suggests the suitability of *Acaulospora* inocula in lowland (*khazans*), *Gigaspora* in midland (*ker*) and *Claroideoglomus* in Upland (*morod*) fields.

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