

## Diversity studies on arbuscular mycorrhizal fungi in vegetable crop plants of Goa, India

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This study was conducted to assess the arbuscular mycorrhizal fungal diversity associated with different vegetable crop plants cultivated in Goa. Fifty one AM fungal species were recovered from rhizosphere soil samples of 27 vegetable crop plants belonging to 10 families from 10 different agricultural sites of Goa during 2008-2009. *Glomus* (26) was the dominant genus followed by *Acaulospora* (16), *Gigaspora* (4) and *Scutellospora* (5) with species number given in parentheses. The maximum spore density was recorded in Cansaulim (1015.01 spores 100g<sup>-1</sup>soil) and minimum was reported in Pernem (394.01spores 100g<sup>-1</sup>soil). The highest number of arbuscular mycorrhizal spores was found in *Zea mays* (95.33 spores100g<sup>-1</sup>soil) in Taleigao and least was recovered in *A. viridis* (12.33 spores 100g<sup>-1</sup>soil) in Taleigao. *Acaulospora scrobiculata* was recorded in all ten sites in 24 vegetables and was the dominant species in six sites. Species richness was maximum in Netravali (28species<sup>-site</sup>). Simpsons and Shanon-Wiener Diversity Indices of arbuscular mycorrhizal fungi were highest in Netravali respectively.

**Key words** – Agricultural sites – dominant genus – rhizosphere soil samples – species richness – spore density

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### Introduction

Arbuscular mycorrhizal (AM) fungi belonging to the phylum Glomeromycota (Wang & Qiu 2006) are vital components of almost all terrestrial ecosystems, forming a mutualistic symbiosis with roots of *ca* 80% of vascular plants (Smith et al. 2003), including vegetable crop plants and agronomically important species (Harrier & Watson 2004). As obligate symbionts AM fungi are dependent upon host plants for fixed carbon (Rezaee et al. 2007). In exchange plants in agricultural and natural ecosystems receive various benefits from AM fungi *viz.*, improvement in the uptake of diffusion limited macronutrients such as P (Rivera et al. 2005) and other minerals such as K, Fe, Cu, Ca, Mg and Zn (George 2000; Liu et al. 2002; Yaseen et al. 2011), increase in the

ability to overcome biotic and abiotic stresses (Pojo & Azcon 2007) such as protection of plants against soil-borne diseases, water relations and soil aggregation and enhancement in crop growth and yield (Douds et al. 2005). Application of AM fungi has resulted in enhanced productivity in cereals, pulses, oilseeds, vegetables and ornamental plants (Boddington & Dodd 2000).

AM fungal diversity shows variation dependent upon plant species (Blaszkowski 1994). In particular, AM fungi are important in organic and sustainable farming systems that rely on biological processes rather than agrochemicals (Harrier & Watson 2004), thus offering a great potential for sustainable agricultural system (Khalil et al. 1992). A better understanding of the field study based on



**Fig. 1** – Map of Goa showing study sites

AM fungal diversity associated with agronomic crops is necessary. The objective of this study is to assess the AM fungal diversity associated with different vegetable crop plants cultivated in Goa. AM fungal colonization and soil analysis of rhizosphere soils of the agricultural fields was also determined.

### Materials and methods

Rhizosphere soil and root samples of 27 cultivated vegetable crops were collected from 10 different sites *viz.*, Cansaulim (S-I), Dhargal (S-II), Old-Goa (S-III), Taleigao (S-IV), Agassim (S-V), Farmagudi (S-VI), Porvorim (S-VII), Netravali (S-VIII), Arossim (S-IX), and Goa-Velha (S-X), during 2008-2009 (Fig. 1). The climate is dry tropical, warm and humid with loamy-sandy soil. Mean temperature range from 20°C - 35°C, with an average rainfall of 2500mm.

Soil samples were collected from a depth of 0-25cm from the selected study sites. Soil pH was measured by pH meter in a 1:1 H<sub>2</sub>O solution (LI 120 Elico, India). Electrical Conductivity (EC) was measured using Conductivity meter (CM-180 Elico, India).

Organic carbon (C) and available phosphorus (P) were analyzed using the standard soil analysis techniques *viz.*, Walkley & Black (1934) rapid titration method and Bray & Kurtz method (1945), respectively. Available potassium (K) was estimated by ammonium acetate method (Hanway & Heidal 1952) using flame photometer (Systronic 3292). Available zinc (Zn), copper (Cu), manganese (Mn) and iron (Fe) were quantified by DTPA-CaCl<sub>2</sub>-TEA method (Lindsay & Norwell 1978) and boron (B) by the hot water soluble method (Berger & Truog 1939) using Atomic Absorption Spectrophotometer (AAS 4139).

Root samples were processed for AM fungal colonization using the method of Koske & Gemma (1989). The stained roots were examined using an Olympus research microscope BX 41 (100X - 1000X) for AM fungal structures and percent root length colonization was determined following the slide method (Giovannetti & Mosse 1980). AM fungal spores were isolated by wet sieving and decanting method (Gerdemann & Nicolson 1963).

Intact and unparasitized spores were used for the quantification of spore density and

**Table 1** Soil chemical analysis in the agricultural sites in Goa.

Sites	pH	EC m/ mhos/cm	Macro-nutrients			Micro-nutrients (ppm)				
			Organic Carbon %	P <sub>2</sub> O <sub>5</sub> ppm	K <sub>2</sub> O Kg/Ha	Zn	Fe	Mn	Cu	B
Cansaulim	6.8	0.577	0.35	29.93	291.2	0.84	99.36	18.85	0.50	0.23
Dhargal	5.7	0.156	2.50	13.30	896.0	1.45	63.84	11.52	3.42	0.72
Old-Goa	6.1	0.231	1.83	9.97	884.8	2.23	110.26	13.55	1.51	0.47
Taleigao	6.5	0.707	0.32	17.95	369.6	1.50	43.00	30.20	1.80	0.21
Agassim	6.8	0.818	0.52	33.25	358.4	6.42	58.96	82.10	7.47	0.60
Farmagudi	4.8	0.293	1.83	26.60	470.4	5.40	69.36	145.20	7.24	0.60
Porvorim	5.6	0.210	0.28	29.93	67.2	0.29	117.14	28.38	1.23	0.17
Netravali	7.0	0.592	1.74	73.16	963.2	2.89	71.28	93.88	3.31	0.33
Arossim	7.0	0.527	0.48	33.25	694.4	3.04	64.42	20.04	0.72	0.27
Goa-Velha	6.8	0.757	0.41	30.13	257.6	1.32	56.62	15.42	1.21	0.31

taxonomy of AM fungi. The identification of AM spores was based on morphotaxonomic criteria using available literature (Schenck & Perez 1990; Morton & Benny 1990; Almeida & Schenck 1990; Rodrigues & Muthukumar 2009).

### Statistical analysis

Data were statistically analyzed for standard deviation. Variation in AM fungal root colonization in relation to spore density was determined by Pearson's correlation coefficient using WASP (Web Based Agricultural Package) 2.0 to  $P \leq 0.05$  significance level.

Diversity studies were carried out for AM fungal species richness (species richness of AM fungi is the number of different species present in a particular site), species evenness (the measure of the relative abundance of the different species making up the richness of an area), Simpsons's Diversity Index ( $I-D$ ) and Shannon-Wiener Diversity Index ( $H$ ) using PAST (Paleontological Statistics Software Package for Education and Data Analysis) version 2.14 (Hammer et al. 2001).

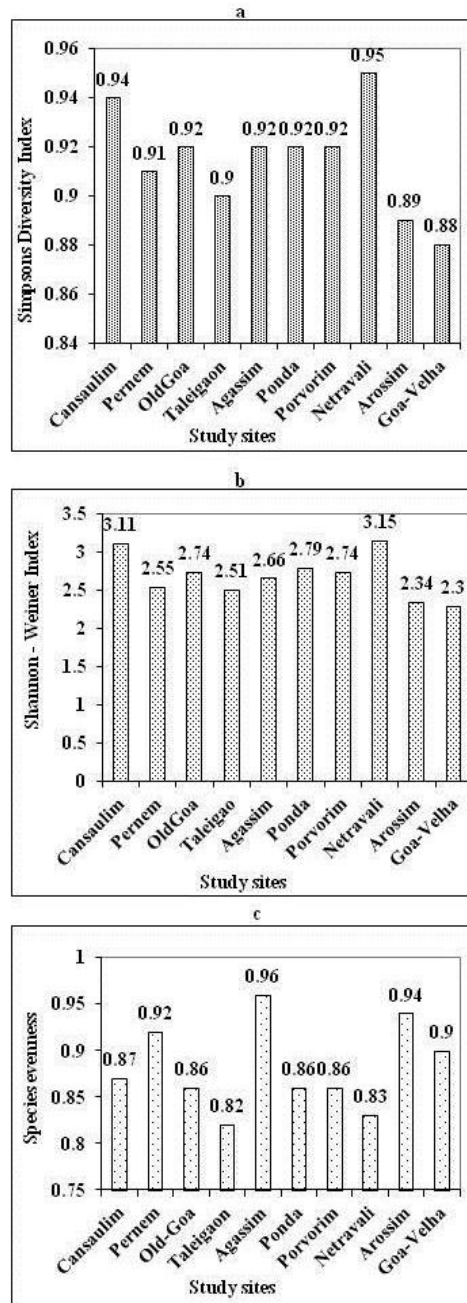
### Results

Results of the soil analysis are shown in

Table 1. Soil pH was found to be acidic to neutral ranging from 4.8 to 7. Available soil-P was found to be high, ranging from 9.97 to 73.16 ppm. Available K ranged from 67.2 to 963.2 Kg/Ha. Micronutrients content Fe, Mn, Zn, Cu and B was variable at the study sites.

Twenty two of the 27 vegetable crops undertaken for the study, showed AM colonization (Fig. 3 a, b). Maximum root colonization was observed in *Zea mays* (68.33%) at S-IV and minimum in *Lagenaria siceraria* (36%) at S-IX (Table 2). AM colonization was absent in five vegetable crops, viz., *Amaranthus cruentus*, *A. viridis*, *Brassica rapa*, *Raphanus sativus* and *Spinacia oleraceae* (Table 2) belonging to Amaranthaceae and Brassicaceae. Pearson's correlation coefficient for AM root colonization and spore density showed significance in all the sites.

Maximum spore density was recorded in S-I (1015.01 spores 100 g<sup>-1</sup> soil) and minimum in S-II (394.01 spores 100 g<sup>-1</sup> soil) (Table 3). The highest number of AM spores was found in *Z. mays* (95.33 spores 100 g<sup>-1</sup> soil) in S-IV, and the least recovered in *A. viridis* (12.33 spores 100 g<sup>-1</sup> soil) in S-IV (Table 3). Highest number of AM fungal species were recovered from *Abelmoschus*



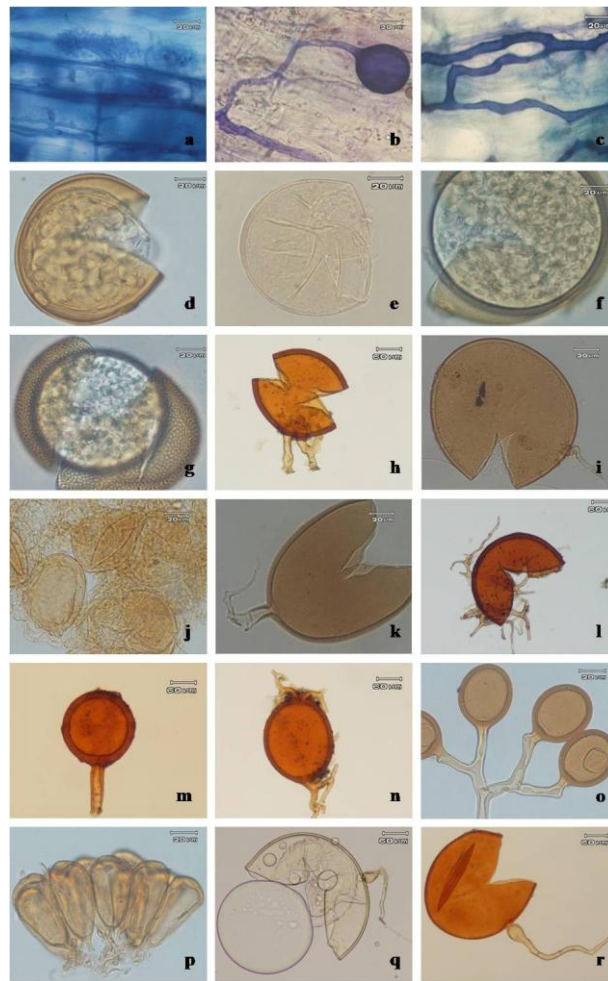
**Fig. 2** – AM fungal diversity indices in vegetable crop plants in agricultural sites of Goa **a** Simpson's Diversity Index **b** Shannon-Wiener Diversity Index **c** Species evenness.

*esculentus* (9) in S-VIII, *Cucumis sativus* (9) in S-III and *C. melo* (9) in S-VI, and the least number (2) isolated from *A. viridis*, *A. cruentus*, *R. sativus* in S-V, S-X and *B. rapa* in S-IX (Table 3).

A total of 51 AM fungal species (Fig. 3 c to z) were recorded from ten agricultural sites (Table 3) and *Glomus* spp. (26) was the dominant genus followed by *Acaulospora* spp. (16), *Gigaspora* spp. (4) and *Scutellospora* spp. (5). *Acaulospora appendicula* and *Glomus albidum* were isolated only once in *A.*

*esculentus* from site S-VIII and *G. flavisporum* was recorded only once in *Luffa acutangula* in S-III. *A. rugosa* was reported only in S-IV, in two vegetables, *L. siceraria* and *Z. mays*. *Acaulospora scrobiculata* was recorded in all sites, in the greatest number of vegetable crops (24) and was dominant in six sites. *Acaulospora nicolsonii* was also found in all sites in 19 different vegetables.

The abundant AM species recorded were *A. scrobiculata* in S-I (94), S-II (53), S-V (68), S-VI (87), S-VII (94), S-VIII (58), *A.*



**Fig. 3** – AM fungal root colonization and spores isolated from rhizosphere soils of vegetable crop plants. **a–c** intra-radicle morphological root colonization: arbuscule, vesicle, hypha. **d–g** *Acaulospora* species: *A. dilatata*, *A. myriocarpa*, *A. rehmi*, *A. scrobiculata*. **h–p** *Glomus* species: *G. ambisporum*, *G. coremioides*, *G. constrictum*, *G. fasciculatum*, *G. formosanum*, *G. geosporum*, *G. multicaulis*, *G. rubiformis*, *G. taiwanensis*. **q–r** *Gigaspora* species: *Gi. albida*, *Gi. decipiens*.

**Table 2** Percent root colonization in vegetable crop plants of Goa.

Vegetable crops	S-I	S-II	S-III	S-IV	S-V	S-VI	S-VII	S-VIII	S-IX	S-X
<i>Allium cepa</i> L. (Liliaceae)	40.00 ± 6.08	nd	nd	nd	nd	nd	nd	nd	49.33 ± 7.63	nd
<i>Amaranthus cruentus</i> L. (Amarathaceae)	-	-	-	-	-	-	nd	-	-	-
<i>Abelmoschus esculentus</i> (L.) Moench. (Malvaceae)	46.33 ± 9.50	53.00 ± 5.00	41.33 ± 9.45	52.67 ± 10.01	50.33 ± 14.74	57.00 ± 10.58	nd	52.33 ± 15.33	53.38 ± 13.57	56.33 ± 10.40
<i>Arachis hypogaea</i> L. (Fabaceae)	nd	nd	nd	nd	nd	nd	67.00 ± 11.00	nd	nd	nd
<i>Amaranthus viridis</i> L. (Amarathaceae)	-	nd	nd	-	-	-	nd	-	-	-
<i>Brassica rapa</i> L. (Brassicaceae)	-	nd	-	-	nd	nd	nd	-	-	-
<i>Capsicum annuum</i> L. (Solanaceae)	55.33 ± 8.50	44.33 ± 10.50	43.00 ± 7.00	55.67 ± 6.50	nd	nd	59.00 ± 13.00	50.33 ± 10.69	48.00 ± 12.16	54.00 ± 10.00

<i>Coccinia grandis</i> (L.) J.Voigt (Cucurbitaceae)	45.33 ± 6.50	56.67 ± 10.01	54.33 ± 8.50	52.00 ± 4.00	nd	nd	65.00 ± 9.16	nd	49.00 ± 13.45	nd
<i>Cucumis melo</i> L. (Cucurbitaceae)	53.00 ± 5.00	nd	nd	nd	56.33 ± 9.07	46.00 ± 12.00	nd	nd	nd	nd
<i>Cucurbita moschata</i> Duchesne ex Poir. (Cucurbitaceae)	49.67 ± 6.02	nd	nd	nd	57.00 ± 10.14	49.33 ± 8.73	nd	nd	nd	nd
<i>Cucurbita pepo</i> Duchesne. (Cucurbitaceae)	nd	nd	nd	nd	nd	54.33 ± 12.50	nd	nd	nd	51.00 ± 12.00
<i>Cucumis sativus</i> L. (Cucurbitaceae)	51.67 ± 6.42	57.67 ± 13.01	67.33 ± 8.73	nd	nd	50.66 ± 12.58	53.00 ± 14.00	nd	nd	nd
<i>Cyamopsis tetragonoloba</i> (L.) Taub. (Fabaceae)	56.33 ± 4.50	61.33 ± 10.21	58.33 ± 11.50	61.66 ± 10.59	58.00 ± 12.28	63.67 ± 8.02	56.00 ± 11.00	56.33 ± 11.01	48.51 ± 8.02	57.33 ± 10.06
<i>Daucus carota</i> L. (Apiaceae)	nd	nd	nd	64.67 ± 10.26	nd	nd	nd	nd	nd	nd
<i>Ipomoea batatas</i> (L.) Lam. (Convolvulaceae)	64.00 ± 6.00	nd	nd	53.00 ± 5.00	62.67 ± 15.01	nd	nd	51.00 ± 15.71	nd	58.00 ± 11.00
<i>Lagenaria siceraria</i> (Molina) Standl. (Cucurbitaceae)	51.00 ± 7.21	nd	nd	38.00 ± 12.52	52.33 ± 14.50	nd	52.67 ± 14.01	nd	36.00 ± 14.52	56.33 ± 10.50
<i>Luffa acutangula</i> (L.) Roxb. (Cucurbitaceae)	nd	nd	57.67 ± 10.26	nd	nd	52.33 ± 13.50	56.67 ± 13.05	nd	nd	nd
<i>Lycopersicon esculentum</i> Mill. (Solanaceae)	41.67 ± 8.96	nd	nd	nd	nd	nd	56.33 ± 9.45	nd	49.00 ± 8.80	nd
<i>Momordica charantia</i> Descourt. (Cucurbitaceae)	nd	45.33 ± 9.50	62.00 ± 7.54	nd	57.00 ± 13.00	49.00 ± 6.08	53.00 ± 7.00	nd	nd	nd
<i>Raphanus sativus</i> L. (Brassicaceae)	-	nd	nd	-	-	-	-	nd	-	-
<i>Solanum melongena</i> L. (Solanaceae)	49.33 ± 10.50	64.33 ± 10.78	61.00 ± 9.16	61.67 ± 11.59	50.67 ± 8.20	nd	62.00 ± 7.54	52.00 ± 12.28	55.33 ± 11.06	52.23 ± 15.04
<i>Spinacia oleraceae</i> L. (Amaranthaceae)	-	nd	nd	-	-	nd	nd	nd	nd	-
<i>Trichosanthus L.</i> <i>Cucumerina</i> (Cucurbitaceae)	nd	nd	nd	nd	53.33 ± 14.04	46.00 ± 10.00	nd	nd	nd	nd
<i>Trigonella foenum-graecum</i> L. (Fabaceae)	52.33 ± 7.50	nd	nd	48.33 ± 10.50	nd	nd	nd	nd	nd	nd
<i>Vigna sesquipedalis</i> (L.)Verdc. (Fabaceae)	64.00 ± 6.00	60.00 ± 10.00	nd	54.67 ± 10.01	57.00 ± 11.53	47.00 ± 13.74	56.00 ± 10.53	nd	nd	nd
<i>Vigna unguiculata</i> (L.) Walp. (Fabaceae)	63.00 ± 6.55	nd	nd	52.00 ± 12.12	58.00 ± 9.53	55.00 ± 12.16	56.33 ± 8.32	54.67 ± 12.01	nd	46.00 ± 14.52
<i>Zea mays</i> L. (Poaceae)	55.33 ± 7.76	nd	nd	68.33 ± 14.01	nd	nd	52.67 ± 11.37	nd	nd	nd

**Legend:** - = AM colonization was absent, nd = Vegetable crop plants not detected in the sites, ± = std.dev. n = 3 S = site; S-I = Cansaulim, S-II = Dhargal, S-III = Old-Goa, S-IV = Taleigao, S-V = Agassim, S-VI = Farmagudi, S-VII = Porvorim, S-VIII = Netravali, S-IX = Arossim, S-X = Goa-Velha.

*nicolsonii* S-IX (66), *A. undulata* S-IV (101), *G. maculosum* S-III (69) and *G. manihotis* S-X (107) (Table 4).

Species richness was maximum in S-VIII (28 species site<sup>-1</sup>) and minimum in S-IX and S-X (11 species site<sup>-1</sup>). Simpson's Diversity Index was high in S-VIII (0.95) (Fig. 2a) and Shannon-Wiener Diversity Index of AM fungi was more in S-VIII (3.15) (Fig. 2b). Species evenness of AM fungal species was high in S-V (0.96) as compared to the other nine sites (Fig. 2c).

## Discussion

Available soil-P was found to be high in the agricultural fields which may be due to frequent fertilization of soils in the field (Mathimaran et al. 2007). Fertilizer management has a direct effect on the performance of AM fungi in a system (Miller & Jackson 1998) where generally P fertilizer reduces AM fungal colonization and effectiveness, varying with species (Schubert & Hayman 1986). AM association and spore numbers can also be affected by rapid changes in soil nutrients (Abbott & Robson 1991). Studies on the increased uptake of K, Mg, Fe and other mineral elements by AM fungi have been reported in the previous studies (Smith & Read 1997; Clark & Zeto 2000). Enhancement of Zn and Cu uptake by AM plants, attribute to the better uptake and transport in external hyphae to the host plant is also reported (Cumming & Ning 2003).

AM colonization was absent in family belonging to Amaranthaceae and Brassicaceae. This may be due to the release of root exudate by these two families, (Sanon et al. 2009) which must have lead to the reduced susceptibility of plants to mycorrhization (Tester et al. 1987).

The variations in AM fungal root colonization and spore density may be due to habitat differences, environmental factors, soil fertility, application of fertilizers (Brundrett 1991) or soil disturbance in the sites (Jasper et al. 1991; Boddington & Dodd 2000). Howeler et al. (1987) also observed large variation in root colonization and spore numbers in rhizosphere soils of crop species grown in different agricultural sites. Therefore P application rates have to be carefully tuned

within the frames of integrated soil fertility management so as not to dramatically decrease continuing benefits of plants from mycorrhizal symbiosis (Mathimaran et al. 2007).

In the present study *Glomus* spp. (26) was the dominant genus which may be due to the fact that it possesses the ability to germinate in a wide range of temperature and pH (Wang & Tschen 1997) followed by *Acaulospora* spp. (16), *Gigaspora* spp. (4) and *Scutellospora* spp. (5). Some of the species, *Acaulospora appendicula*, *A. rugosa*, *Glomus albidum*, *G. flavisporum* was recorded only once in site and in particular vegetable crops. The rare occurrence of AM fungal species only in one site and/or in particular vegetable crops may be due to the acclimatization of a particular AM fungal genus/species to a particular location (Brundrett 1991).

*Acaulospora nicolsonii* and *Acaulospora scrobiculata* was recorded in all sites. Previous studies reported that *Acaulospora* species are often associated with acidic soils (Morton 1986; Abbott & Robson 1991). The present study however, shows that *Acaulospora* species were present in both acid soils ranging from 6.1 to 6.8 and in neutral soils with pH 7.0. A similar diversity study reported that *Acaulospora* species were found in alkaline soil with pH 7.2 (Chetan et al. 2008). Wang et al. (1993) found that pH had little effect on mycorrhizal colonization of oat and potato, but markedly altered the species diversity of the colonizing fungi.

There was variation in abundant AM species recorded in different sites. These variation in spore abundance of different AM fungi in different sites was observed in earlier studies (Schenk & Kinloch 1980; Chetan et al. 2008). Mathimaran et al. 2007, reported higher spore abundance of *Acaulospora* species in rotation of *Z. mays* and *Crotolaria* spp. in agricultural field.

It has been reported that species richness index is dependent on the sample size, the greater the number of samples collected, the greater the number of species is likely to be recovered (Radhika & Rodrigues 2010). The variation in AM fungal diversity in rhizosphere soils in the different sites may be due to other factors such as pH, available P or others nutrients in the soil (Chetan et al. 2008). The

**Table 3** AM fungal species and spore density in agricultural sites of Goa.

Sites	<i>Allium cepa</i>	<i>Amaranthus cruentus</i>	<i>Amaranthus esculentus</i>	<i>Arachis hypogaea</i>	<i>Amaranthus viridis</i>	<i>Brassica rapa</i>	<i>Capsicum annuum</i>
S-I	<i>A. di, A. sc, G. ho</i> 44.33±1.15	<i>A. me, G. cla, S. bi</i> 16.67±4.16	<i>A. de, A. sc, G. mac</i> 66.67±6.43	nd	<i>A. di, G. con, G. geo</i> 18.67±3.21	<i>A. di, A. me, G. tai</i> 16.33±1.15	<i>A. sc, G. etu, G. geo, G. glo, S. bi</i> 73.00±4.36
S-II	nd	<i>G. for, G. fas, G. sin</i> 19.00±2.65	<i>A. sc, G. cor, G. mos</i> 32.67±2.52	nd	nd	nd	<i>G. mon, G. mul, G. tai</i> 45.67±1.5)
S-III	nd	<i>A. me, A. un, G. sin, G. tai</i> 21.00±1.00	<i>A. me, A. fo, A. sc, G. mac, G. mul</i> 44.66±8.52	nd	nd	<i>A. di, A. sc, G. mac, G. mul, G. tai</i> 20.33±5.53	<i>A. di, A. ni, G. con, G. for, G. pac</i> 77.33±7.02
S-IV	nd	<i>A. ni, A. my, A. sc, A. un</i> 17.67±10.53	<i>A. di, A. sp, A. un, Gi. gi</i> 56.00±12.65	nd	<i>A. sp, A. my, A. un</i> 12.33±9.52	nd	<i>A. sc, A. sp, A. un, G. sin, Gi. gi</i> 57.33±2.08
S-V	nd	<i>A. me, G. mic</i> 14.33±2.08	<i>A. ni, A. sc, G. ge.</i> 21.33±3.21	nd	<i>A. di, A. sc</i> 17.67±1.53	nd	nd
S-VI	nd	<i>A. de, A. di, A. ni, A. sc</i> 30.33±1.53	<i>A. de, A. di, G. cor</i> 35.67±4.16	nd	<i>A. sc, G. clav, G. geo</i> 27.00±2.00	nd	nd
S-VII	nd	nd	nd	<i>A. di, A. sc, G. clav, G. geo, Gi. gi</i> 76.00±4.16	<i>A. di, A. sc, G. clav</i> 19.00±3.61	nd	<i>A. di, A. un, G. geo</i> 30.67±3.06
S-VIII	nd	<i>A. fo, A. sc, G. mac, G. macu, G. pac, G. tai, G. al</i> 23.13±2.65	<i>A. ap, A. de, A. sc, G. alb, G. cal, G. fas, G. geo, G. hoi, G. mac</i> 58.32±3.12	nd	<i>A. ni, G. fas, G. geo, G. mac, G. mic, Gi. al, S. gr</i> 19.00±2.00	<i>A. ni, A. sc, G. cal, G. fas, G. geo, G. mac, S. gr</i> 18.33±2.52	<i>G. clar, G. fas, G. glo, G. hoi, G. mac, G. mul, G. mos, S. gr</i> 84.67±4.16
S-IX	<i>A. de, A. sc, G. geo, G. mac</i> 59.67±1.53	<i>A. ni, G. cor, G. rub</i> 18.00±2.65	<i>A. me, A. ni, A. sc</i> 29.67±2.08	nd	<i>A. sc, A. ni, G. cor</i> 22.00±3.00	<i>A. de, G. fas</i> 20.77±4.73	<i>A. sc, G. cor, G. tai</i> 40.00±2.00
S-X	nd	<i>A. ni, A. sc</i> 14.67±2.51	<i>A. me, A. ni, G. fas, S. gr</i> 58.00±3.00	nd	<i>A. me, G. fas</i> 19.67±4.50	<i>A. ni, G. geo, G. mul</i> 16.33±4.04	<i>A. el, A. sc, G. mul</i> 44.33±4.04

Sites	<i>Coccinia grandis</i>	<i>Cucumis melo</i>	<i>Cucurbita moschata</i>	<i>Cucurbita pepo</i>	<i>Cucumis sativus</i>	<i>Cyamopsis tetragonoloba</i>	<i>Daucus carota</i>
S-I	<i>A. de, G. cla, G. cor, G. etu, G. geo, G. mos</i> 55.00±1.00	<i>A. di, A. ni, G. fas, G. cor, G. tai, Gi. dec</i> 82.67±6.6)	<i>A. me, A. mo, G. mac</i> 50.00±2.00	nd	<i>A. me, A. sc, G. mac, G. tai,</i> 58.67±3.21	<i>A. di, Gi. ra, S. gr</i> 40.00±8.00	nd



S-II	<i>A. ni, A.sc, G. fas, G.mac, G. sin, G. tai</i> 63.67±1.53	nd	nd	nd	<i>A. den, A. ni, A. sc, A. tu, G. mul, G. tai</i> 49.00±1.00	<i>A. tu, G. fas, G. mac</i> 42.33 ± 1.53	nd
S-III	<i>A. sc, G. con, G. macu, G. rub</i> 60.33±1.53	nd	nd	nd	<i>A. fo, A. ni, A. sc, G.con, G.fas, G. mul, G. macu, G. pac, G. tai</i> 60.67±1.53	<i>A. de, A. fo, G. con, G. geo, G. for</i> 50.33±4.16	nd
S-IV	<i>A. my, A. ni, A. sc, A. un</i> 60.00±2.00	nd	nd	nd	nd	<i>A. el, A. me, A. sp, A. un, G. mos, G. sin, Gi. gi</i> 50.67±2.08	<i>A. di, A. me, A. my, A. sc, A. sp, A. un</i> 29.67±1.53
S-V	nd	<i>G. macu, G. sin, G. tai</i> 49.33±7.57	<i>A. de, G. mac, G. mic</i> 56.66±5.69	nd	nd	<i>A. de, A. me, G. mic</i> 21.33±2.08	nd
S-VI	nd	<i>A. ni, A. sc, G. cor, G. fas, G. for,, G. macu, G. tai, G. mul, S. ni</i> 71.67±4.93	<i>A. el, A. sc, G. macu</i> 52.67±1.53	<i>A. el, G. for, G. geo, G. macu, G. tai</i> 59.00±7.50	<i>A. di, A. sc, G. mac</i> 51.33±3.79	<i>G. mul, G. geo, A. ni</i> 52.33±2.52	nd
S-VII	<i>G. geo, G. mul, G. sin,</i> 49.00±5.10	nd	nd	nd	<i>A. sc, A. tu, G. clav</i> 54.33±5.03	<i>A. de, A. sc, A. un, G. mul</i> 61.00±3.61	nd
S-VIII	nd	nd	nd	nd	nd	<i>A. sc, G. amb, G. clar, G. macu, G. mul, Gi. al, S. he</i> 72.33±2.52	nd
S-IX	<i>A. me, G. cor, G. geo</i> 26.32±1.53	nd	nd	nd	nd	<i>A. dil, G. geo, G. macu</i> 42.00±2.00	nd
S-X	nd	nd	<i>A. el, A. fo, A. ni, A. sc, G. geo, G. man</i> 66.67±4.04	nd	nd	<i>A. fo, G. geo, S. gre</i> 59.67±1.53	nd

Sites	<i>Ipomoea batatas</i>	<i>Lagenaria siceraria</i>	<i>Lycopersicon acutangula</i>	<i>Luffa esculentum</i>	<i>Momordica charantia</i>	<i>Raphanus sativus</i>	<i>Solanum melongena</i>
S-I	<i>A. di, A. sc, G. cla, G. geo, G. sin, Gi. de</i> 75.67±6.11	<i>A. sc, G. cor, G. tai</i> 57.67±1.52	nd	<i>G. cal, S.bi, S. gr</i> 44.00±6.56	nd	<i>A. me, G. tai, S. ca</i> 21.33±3.79	<i>A. me, G. etu, G. macu, S.ca</i> 91.33±3.21
S-II	nd	nd	nd	nd	<i>A. sc, A.sp, G. mos</i> 36.67±4.16	nd	<i>G. for, G. sin, G. tai</i> 55.33±2.30

S-III	nd	nd	<i>A. de, A. fo, A. sc, G. for, G. macu, G. mul, G. pac, G. fla</i> 79.33±3.79	nd	<i>A. me, A. sc, G. macu</i> 49.00±2.00	nd	<i>A. de, A. me, G. fas, G. geo</i> 54.33±2.08
S-IV	<i>A. me, A. my, A. ni, A. re, A. un, G. mos</i> 29.00±1.00	<i>A. me, A. ru, A. sp, A. u n</i> 86.67±0.58	nd	nd	nd	<i>A. el, A. my, A. un</i> 15.33±3.52	<i>A. el, A. me, A. un, G. sin</i> 42.33±2.52
S-V	<i>A. di, A. sc, G. clar, G. mac</i> 76.00±7.00	<i>A. me, A. sc, G. fas</i> 45.33±3.51	nd	nd	<i>A. di, A. me, A. sc</i> 30.33±1.53	<i>A. me, A. sc</i> 18.67±1.53	<i>A. me, A. sc, G. geo, G. macu</i> 91.00±4.36
S-VI	nd	nd	<i>A. di, A. sc, A. sp, G. amb, G. macu, S. ni</i> 58.33±7.64	nd	<i>A. ni, A. sc, G. cor, G. clav, G. geo, G. mac</i> 52.67±3.05	<i>A. di, A. ni, A. sc, S. gr, S. ni</i> 16.67±1.53	nd
S-VII	nd	<i>A. me, A. sc, G. geo, Gi. de</i> 25.00±4.00	<i>A. ni, G. mon, G. sin, G. tai</i> 63.67±4.73	<i>A. den, A. un, G. mul, Gi. de</i> 36.00±2.65	<i>G. clav, G. cor, Gi. de</i> 59.33±2.08	<i>A. me, G. cor, G. mon</i> 15.27±1.43	<i>A. tu, G. clav, Gi. gi</i> 32.67±3.05
S-VIII	<i>A. my, A. sc, G. fas, G. geo, Gi. al, S. he</i> 83.67±3.73	nd	nd	nd	nd	nd	<i>A. den, A. di, A. me, A. sc, G. pac, Gi. al, S. gr</i> 78.00±3.00
S-IX	nd	<i>A. di, G. geo, G. tai</i> 73.67±5.69	nd	<i>A. ni, G. cor, G. fas</i> 19.00±2.00	nd	<i>A. me, A. ni, A. sc</i> 14.33±2.08	<i>A. me, A. ni, G. macu</i> 58.00±2.00
S-X	<i>A. el, A. sc, G. fas, G. geo, G. mul</i> 73.67±3.79	<i>A. sc, G. fas, S. gr</i> 59.67±3.15	nd	nd	nd	<i>G. fas, G. mul</i> 13.00±3.60	<i>A. el, A. sc, G. geo, G. man</i> 41.00±3.60

Sites	<i>Spinacia oleraceae</i>	<i>Trichosanthes cucumerina</i>	<i>Trigonella foenum-graecum</i>	<i>Vigna sesquipedalis</i>	<i>Vigna unguiculata</i>	<i>Zea mays</i>	Total spore density
S-I	<i>A. me, A. sc, Gi. ra, S. ca, S. gr</i> 22.67±4.16	nd	<i>A. sc, Gi. ra, S. ca</i> 25.67±3.79	<i>A. me, A. sc, G. clar, G. macu</i> 57.33±5.03	<i>A. me, A. sc, Gi. gi, S. gr</i> 68.00±3.45	<i>A. me, A. sc, G. con, Gi. de</i> 73.33±5.13	1015.01
S-II	nd	nd	nd	<i>A. sc, G. cor, G. for, G. mul, G. sin</i> 49.67±4.51	nd	nd	394.01
S-III	nd	nd	nd	nd	nd	nd	517.31

S-IV	<i>A. di</i> , <i>A. my</i> , <i>A. sc</i> , <i>A. un</i> 27.67±4.16	nd	<i>A. di</i> , <i>A. me</i> , <i>A. my</i> , <i>A. sp</i> , <i>A. un</i> 59.67±4.51	<i>A. me</i> , <i>A. sc</i> , <i>A. tu</i> , <i>G. sin</i> , <i>Gi. gi</i> 68.67±5.51	nd	<i>A. di</i> , <i>A. ni</i> , <i>A. mo</i> , <i>A. ru</i> , <i>A. un</i> , <i>G. sin</i> 95.33±3.51	613.01
S-V	<i>A. sc</i> , <i>G. macu</i> , <i>G. mul</i> 23.33±4.16	<i>A. ni</i> , <i>G. mon</i> , <i>G. sin</i> , <i>G. tai</i> 51.33±3.21	nd	<i>A. sc</i> , <i>G. sin</i> , <i>G. tai</i> 39.00±4.00	<i>G. mon</i> , <i>A. dil</i> , <i>G. fas</i> 56.00±8.54	nd	611.64
S-VI	nd	<i>A. di</i> , <i>G. for</i> , <i>G. geo</i> , <i>Gi. al</i> 58.00±2.00	nd	<i>A. sc</i> , <i>G. cor</i> , <i>G. mul</i> 30.33±2.52	<i>A. de</i> , <i>A. di</i> , <i>A. ni</i> , <i>G. geo</i> 30.67±2.08	nd	574.34
S-VII	nd	nd	nd	<i>A. ni</i> , <i>A. sc</i> , <i>A. tu</i> , <i>Gi. de</i> 24.67±3.51	<i>A. tu</i> , <i>G. clav</i> , <i>G. mul</i> , <i>G. tai</i> 43.00±4.59	<i>A. sc</i> , <i>G. mul</i> , <i>Gi. gi</i> , <i>S. gr</i> 52.33±3.51	641.94
S-VIII	nd	nd	nd	nd	<i>A. me</i> , <i>A. fo</i> , <i>A. ni</i> , <i>A. sc</i> , <i>G. fas</i> , <i>S. gr</i> , <i>S. ca</i> , <i>S. he</i> 62.67±2.08	nd	499.8
S-IX	nd	nd	nd	nd	nd	nd	423.43
S-X	<i>A. di</i> , <i>A. sc</i> , <i>G. geo</i> 21.33±3.21	nd	nd	nd	<i>A. sc</i> , <i>G. geo</i> , <i>G. man</i> 56.33±6.02	nd	544.34

**Legend:** S = site; S-I = Cansaulim, S-II = Dhargal, S-III = Old-Goa, S-IV = Taleigao, S-V = Agassim, S-VI = Farmagudi, S-VII = Porvorim, S-VIII = Natravali, S-IX = Arossim and S-X = Goa-Velha, nd = Vegetable crops not detected in sites.

**AM species :** *A. ap* = *Acaulospora appendicula*, *A. de* = *A. delicata*, *A. den* = *A. denticulata*, *A. di* = *A. dilatata*, *A. el* = *A. elegans*, *A. fo* = *A. foveata*, *A. me* = *A. mellea*, *A. my* = *A. myriocarpa*, *A. mo* = *A. morrowiea*, *A. ni* = *A. nicolsonii*, *A. re* = *A. rehmi*, *A. ru* = *A. rugosa*, *A. sp* = *A. spinosa*, *A. sc* = *A. scrobiculata*, *A. tu* = *A. tuberculata*, *A. un* = *A. undulata*, *G. amb* = *Glomus ambisporum*, *G. alb* = *G. albidum*, *G. cal* = *G. caledonium*, *G. cla* = *G. claroideum*, *G. clar* = *G. clarum*, *G. clav* = *G. clavispora*, *G. con* = *G. constrictum*, *G. cor* = *G. coremioides*, *G. etu* = *G. etunicatum*, *G. for* = *G. formosanum*, *G. fas* = *G. fasciculatum*, *G. fla* = *G. flavisporum*, *G. geo* = *G. geosporum*, *G. glo* = *G. glomerulatum*, *G. hoi* = *G. hoi*, *G. mac* = *G. maculosum*, *G. mac* = *G. macrocarpum*, *G. man* = *G. manihotis*, *G. mic* = *G. microcarpum*, *G. mon* = *G. monosporum*, *G. mos* = *G. mosseae*, *G. mul* = *G. multicaule*, *G. pac* = *G. pachycaulis*, *G. rub* = *G. rubiformis*, *G. sin* = *G. sinuosa*, *G. tai* = *G. taiwanensis*, *Gi. al* = *Gigaspora albida*, *Gi. de* = *Gi. decipiens*, *Gi. gi* = *Gi. gigantea*, *Gi. ra* = *Gi. ramisporophora*, *S. bi* = *Scutellospora biornata*, *S. ca* = *S. calospora*, *S. gr* = *S. gregaria*, *S. he* = *S. heterogama*, *S. ni* = *S. nigra*.

**Table 4** Spore abundance of AM fungal species in agricultural sites in Goa.

AM species	S-I	S-II	S-III	S-IV	S-V	S-VI	S-VII	S-VIII	S-IX	S-X
<i>A. appendicula</i>	nd	nd	nd	nd	nd	nd	nd	4	nd	nd
<i>A. delicata</i>	52	nd	35	nd	23	19	24	nd	32	nd
<i>A. denticulata</i>	nd	22	nd	nd	nd	nd	19	9	nd	nd
<i>A. dilatata</i>	68	nd	23	32	35	52	44	19	42	39
<i>A. elegans</i>	nd	nd	nd	28	nd	16	nd	nd	nd	46
<i>A. foveata</i>	nd	nd	29	nd	nd	nd	nd	28	nd	32
<i>A. mellea</i>	83	nd	32	36	53	nd	23	26	33	23
<i>A. morrowiea</i>	28	nd	nd	9	nd	nd	nd	nd	nd	nd
<i>A. myriocarpa</i>	nd	nd	nd	88	nd	nd	nd	34	nd	nd

<i>A. nicolsonii</i>	34	27	19	34	23	43	32	24	66	32
<i>A. rehmii</i>	nd	nd	nd	29	nd	nd	nd	nd	nd	nd
<i>A. rugosa</i>	nd	nd	nd	12	nd	nd	nd	nd	nd	nd
<i>A. scrobiculata</i>	94	53	32	24	68	87	94	58	37	77
<i>A. spinosa</i>	nd	14	nd	38	nd	22	nd	nd	nd	nd
<i>A. tuberculata</i>	nd	19	nd	15	nd	nd	21	nd	nd	nd
<i>A. undulata</i>	nd	nd	12	101	nd	nd	36	nd	nd	nd
<i>G. ambisporum</i>	nd	nd	nd	nd	nd	12	nd	5	nd	nd
<i>G. albidum</i>	nd	nd	nd	nd	nd	nd	nd	6	nd	nd
<i>G. caledonium</i>	35	nd	nd	nd	nd	nd	nd	14	nd	nd
<i>G. claroideum</i>	49	nd	nd	nd	34	nd	nd	24	nd	nd
<i>G. clarum</i>	19	nd	nd	nd	nd	nd	nd	8	nd	nd
<i>G. clavispora</i>	nd	nd	nd	nd	nd	27	52	nd	nd	nd
<i>G. constrictum</i>	31	nd	39	nd	nd	nd	nd	nd	nd	nd
<i>G. coremioides</i>	30	37	nd	nd	nd	44	19	nd	54	nd
<i>G. etunicatum</i>	42	nd	nd	nd	nd	nd	nd	nd	nd	nd
<i>G. fasciculatum</i>	37	29	54	nd	46	18	nd	20	33	52
<i>G. flavisporum</i>	nd	nd	6	nd	nd	nd	nd	nd	nd	nd
<i>G. formosanum</i>	nd	22	12	nd	nd	33	nd	nd	nd	nd
<i>G. geosporum</i>	28	nd	33	nd	35	45	46	22	42	59
<i>G. glomerulatum</i>	22	nd	nd	nd	nd	nd	nd	9	nd	nd
<i>G. hoi</i>	13	nd	nd	nd	nd	nd	nd	8	nd	nd
<i>G. macrocarpum</i>	nd	22	nd	nd	44	15	nd	10	nd	nd
<i>G. maculosum</i>	45	nd	69	nd	46	29	nd	19	41	nd
<i>G. manihotis</i>	nd	nd	nd	nd	nd	nd	nd	nd	nd	107
<i>G. microcarpum</i>	nd	nd	nd	nd	53	nd	nd	11	nd	nd
<i>G. monosporum</i>	nd	9	nd	nd	34	nd	10	nd	nd	nd
<i>G. mosseae</i>	78	33	nd	42	nd	nd	nd	19	nd	nd
<i>G. multicaule</i>	nd	28	49	nd	32	31	57	23	nd	45
<i>G. pachycaulis</i>	nd	nd	18	nd	nd	nd	nd	9	nd	nd
<i>G. rubiformis</i>	nd	nd	22	nd	nd	nd	nd	nd	18	nd
<i>G. sinuosa</i>	38	38	17	43	46	nd	24	nd	nd	nd
<i>G. taiwanensis</i>	55	41	16	nd	39	21	21	22	25	nd
<i>Gi. albida</i>	nd	nd	nd	nd	nd	12	nd	23	nd	nd
<i>Gi. decipiens</i>	33	nd	nd	nd	nd	nd	67	nd	nd	nd
<i>Gi. gigantea</i>	26	nd	nd	82	nd	nd	34	nd	nd	nd
<i>Gi. ramisporophora</i>	8	nd	nd	nd	nd	nd	nd	nd	nd	nd
<i>S. biornata</i>	26	nd	nd	nd	nd	nd	nd	nd	nd	nd
<i>S. calospora</i>	16	nd	nd	nd	nd	nd	nd	12	nd	nd
<i>S. gregaria</i>	25	nd	nd	nd	nd	17	19	27	nd	32
<i>S. heterogama</i>	nd	nd	nd	nd	nd	nd	nd	7	nd	nd
<i>S. nigra</i>	nd	nd	nd	nd	nd	31	nd	nd	nd	nd

**Legend:** A - *Acaulospora*, G - *Glomus*, Gi - *Gigaspora*, S - *Scutellospora*, nd = AM species not detected in sites  
S = site; S-I = Cansaulim, S-II = Dhargal, S-III = Old-Goa, S-IV = Taleigao, S-V = Agassim, S-VI = Farmagudi, S-VII = Porvorim, S-VIII = Netravali, S-IX = Arossim, S-X = Goa-Velha.

effectiveness of AM fungal association can be influenced by the crop history of the field, and by crop cultivar (Hendrix et al. 1995).

The AM fungal diversity shown in this study relates to sustainability of an agroecosystem (Sieverding 1990). The greater the diversity, the more benefits conferred to the crops, as the mycorrhizal community will span a broader range of functions (Koide 2000). To optimize management of AM fungi in field conditions there is a need for more information on how agricultural practices influence the variation in AM fungal community development and function in different vegetable crop species. It is necessary to identify AM fungal species in agricultural sites thereby determining the effects of agricultural treatments upon AM fungi and the eventual development of management regimes for these fungi.

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