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Arbuscular Mycorrhizal (AM) fungal diversity on stabilized iron ore mine dumps in Goa, India

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ABSTRACT

The present study was carried out to explore arbuscular mycorrhizal (AM) fungal diversity on stabilized iron ore mine dumps in Goa. A total of 84 plant species belonging to 36 families were examined for the occurrence of AM fungal diversity in two study sites of which 21 plants were common to both sites. All the plants undertaken for study were found to be mycorrhizal. In our study 19 AM fungal species belonging to eight genera, *viz. Acaulospora, Funneliformis, Gigaspora*, *Glomus, Racocetra, Rhizophagus, Sclerocystis* and *Scutellospora* were recovered. *Acaulospora* was dominant genus at both the sites. Based on Relative abundance (RA) and Isolation frequency (IF), *Gigaspora albida* was found to be dominant at site 1, while *Scutellospora heterogama* was dominant at site 2.

KEYWORDS: restoration; spore density; root colonization; mine dumps.

INTRODUCTION

Land is one of the most essential natural resources on which human beings as well as all other terrestrial biomes depend. While society is being benefitted by the extraction of minerals it also causes significant environmental degradation. Mining disrupts the aesthetics of the landscape along with other soil components and results in the destruction of existing vegetation and soil profile (Kundu and Ghose, 1997). Thus, the mineral extraction process should ensure the return in productivity of the affected mines. The negative impacts of mining can be prevented by stabilizing a reject dump through revegetation (Ghose, 1989). Mined land sites are generally known to be nutrient deficient with low plant growth. Hence there is an urgent need to revegetate the mining sites so that there is establishment of stable nutrient cycles from plant growth and microbial process (Singh *et al.*, 2002).

Arbuscular Mycorrhizal (AM) fungi are ubiquitous root symbionts colonizing 80% of the terrestrial plants (Wang and Qui, 2006). This symbiotic relationship benefits both the partners; the host plant provides the fungi with carbohydrates and in return receives mineral nutrients especially P, increase in root surface area for absorption of water (Willis *et al.,* 2013), plant field survival (Karthikeyan and Krishnakumar, 2012).They also improve soil structure, soil water relations, plant growth, yield and reduce fertilizer requirement (Finlay, 2008; Gianinazzi *et al*., 2010; Soka and Ritchie, 2014). Besides they are known to have a crucial role in plant community assembly and succession (Kikvidze *et al*., 2010).

These fungi as allied colonizers and biofertilizers could provide plants with benefits crucial for ecosystem restoration. It is important to use indigenous AM fungal strains which are best adapted to actual soil and climatic conditions to produce site-specific AM fungus inocula. It has now become necessary to quantify the status of existence of indigenous AMF in degraded ecosystems (Mummey *et al*., 2002; Khan, 2004). Only few studies are being carried out to explore the diversity of AM fungi on iron ore mine wastelands of Goa (Rodrigues, 2000; Rodrigues and Bukhari, 1995). However, sites undertaken for the present investigation have not been studied previously. The objective of the present study was to assess the indigenous AM fungal diversity of ten year old mine sites in Goa, India.

METHODOLOGY

The study was carried out at two ten years old stabilized iron ore mines in Pale (North Goa) situated at geographic locations of 15°31'9.13"N Latitude and 74° 2'32.96"E Longitude (Site 1) and 15°29'3.32"N Latitude and 74° 3'35.55"E Longitude (Site 2). The plant species were identified with the help of local and regional floras (Vartak, 1966; Rao, 1985-86; Naithani *et al.*, 1997). Root and rhizosphere soil samples were randomly collected from September 2014 to September 2016.

Three rhizosphere soil samples (0-30cm) were collected for each plant species separately and brought to the laboratory in polyethylene bags. A composite soil sample was prepared by mixing the three soil samples of each plant species. After sieving sample for larger materials and root fragments, each sample was divided into six subsamples. Of these, three subsamples were used for spore extraction and the remaining three were used for soil analysis. Root fragments were used for estimation of AM colonization.

Soil Analyses

Soil pH was measured in soil water suspension (40% w/v) using pH meter (LI120 Elico, India). Electrical conductivity (EC) was measured by using a Conductivity meter (CM-180 Elico, India). Available nitrogen (N) was estimated using the method of Subbiah and Asija, (1956). Available phosphorus (P) was estimated using the method of Bray and Kurtz, (1945).The Hanway and Heidel method (1952) was used to estimate available Potassium (K) using Atomic Absorption Spectrophotometer (Nova 400P, Analytik Jena, Germany). Available micronutrients, *viz.* Zinc (Zn), Copper (Cu), Manganese (Mn) and Iron (Fe) were determined using DTPA $CaCl_2$-TEA method of Lindsay and Norvell, (1978) using Atomic Absorption Spectrophotometer (AAS).

Mycorrhizal colonization

Root samples were hydrolyzed using 10% KOH at 90^0 C for 2 hours followed by acidification in 5N HCl and staining with 0.05% trypan blue overnight (Phillips and Hayman, 1970). Later, stained roots were observed for colonization by mounting on a glass slide using Polyvinyl alcohol lacto glycerol (PVLG) as mountant. Slides were observed using bright field Olympus BX41 research microscope.The

presence of hyphae, arbuscules and/or vesicles confirmed that the root segment was colonized. Per cent AM root colonization (RC) was calculated using the following formula (Read *et al.,* 1976).

$$\% \text{ Root colonization(RC)} = \frac{\text{Number of root segments colonized}}{\text{Total number of root segments examined}} \text{X } 100$$

Isolation and identification of AM fungal spores

Spores were extracted from the rhizosphere soil subsamples separately for each plant using wet sieving and decanting method (Gerdemann and Nicolson, 1963). Extracted spores were mounted on glass slides in PVLG and were observed for spore morphology, wall characteristics, and dimensions under a bright field Olympus BX41 research microscope (40x, 100x and 400x).

The identification of AM fungi was carried out by using the relevant bibliographies (Rodrigues and Muthukumar 2009; Blaszkowski, 2012) and International Collection of Vesicular Arbuscular Mycorrhizal Fungi (INVAM). Names and epithets of AM fungal species were followed according to the recommendation of Schüßler and Walker (2010) and Redecker *et al.* (2013).

Ecological and statistical data analysis

The ecological characteristics of AM fungal species were estimated using the following indices:

a) Relative abundance (RA) = (Number of spores of species/Total number of spores in all soil samples) x 100

b) Isolation frequency (IF) = (Number of soil samples containing particular species/Total number of soil samples analysed) x 100

c) Shannon-Wiener diversity index (H) = $-\Sigma(Pi\ln(Pi))$, where *Pi* is the proportion of individual species that contributes to the total number of individuals(Shannon and Wiener, 1949).

d) Simpson`s diversity index (D) = $1-(\Sigma n\,(n-1)/N\,(N-1))$, where *n* is the number of individuals of a given species and N is the total number of individuals in a community (Simpson, 1949).

e) Species richness (SR) = total number of species in the community.

f) AMF species evenness (E): $\Sigma(H') = H'/H'\max$, where $H'\max = \ln S$, S= SR

Pearson coefficient of correlation (*r*) was calculated to compare the relationship between spore density (SD) and RC, RA and IF and SD and SR using IBM SPSS Statistics 22 software.

RESULTS

Physico-chemical properties of lateritic soils of both the sites revealed that the soils were acidic in nature. All the plant macro- and micro-nutrients analysed were in low levels **(Table1)**.

Table 1: Physico-chemical analyses of mine soils.

Parameter	Study sites	
	Site 1	Site 2
pH	5.45±0.04	5.57±0.19
EC (mS)	0.01±0.12	0.34±0.44
N (g/kg)	0.08±0.04	0.07±0.01
P (g/kg)	0.01±0.00	0.01±0.00
K (g/kg)	0.02±0.00	0.02±0.00
Zn (ppm)	3.25±0.47	3.54±0.18
Cu (ppm)	0.03±0.02	0.01±0.00
Fe (ppm)	21.73±2.67	21.65±1.28
Mn (ppm)	101.77±2.05	78.25±1.63
Ca (ppm)	623.15±6.86	520.36±9.65

Distribution of plant species diversity

Atotal of 84 plants belonging to 36 families were surveyed from the selected sites. Of these, 21 plants were found to be common to both the sites **(Table 2)**.

AM colonization and spore density

AM fungal colonization was recorded in roots of all sampled plant species from both the sites. Both arbuscular and vesicular colonization was recorded. Maximum RC from both the sites *viz.* site 1 (86.67%) and site 2 (80%) was recorded in *Anacardium occidentale*. The least RC was observed in *Adiantum philippense* (11.65%) at site 1 and in *Casuarina equisetifolia* (25%) at site 2.

The highest SD was recorded in *Lantana camara* (304 spores/100g soil) at site 1 and in *A. Occidentale* (299 spores/100g soil) at site 2. Lowest SD was observed in *A. Philippense* (8 spores/100g soil) at site 1 and in *Pteris pellucida* (8 spores/100g soil) at site 2 (**Table 3**).

Diversity and Distribution of AM fungi

A total of 19 AM fungal species belonging to eight genera were recorded from both the sites. *Acaulospora* (6) was found to be dominant genus followed by *Gigaspora* (4), *Sclerocystis* (3), *Scutellospora* (2), *Funneliformis* (1), *Glomus* (1), *Racocetra* (1), *Rhizophagus* (1) with species number given in parenthesis. Highest RA (29.72%) and IF (56.46%) were recorded for *Gigaspora albida* at site 1 and highest RA (35.09%) and IF (42.86%) for *Scutellospora heterogama* at site 2.

Least RA (0.15%) and IF(1.36%) was recorded in *Sclerocystis rubiformis* at site 1, while lowest RA (0.13%) and IF (1.19%) was recorded in *Sclerocystis taiwanensis* at site 2 **(Table 4).** Species richness (17) with species number given in parenthesis was recorded at both the sites.

Pearson's correlation coefficient showed that SD was significantly correlated with RC ($r = 0.499$, $p<0.01$). However, no correlation was observed between SD and SR ($r=0.275$). There existed a positive correlation between RA and IF ($r = 0.952$, $p<0.01$) at site 1. A significant correlation existed between SD and RC ($r = 0.310$, $p<0.05$), RA and IF ($r = 0.899$, $p<0.01$) and, SD and SR ($r = 0.547$, $p<0.01$) on site 2. Shannon-Weiner index (H), Simpson's index of dominance (D), and species evenness were higher on site 1 as compared to site 2 **(Table 5).**

Table 2: Distribution of plant species recorded on a stabilized dump of both the iron ore mine sites.

Family and Plant species	Habit	Location
Acanthaceae		
Andrographis paniculata (Burm.f.)Nees	Herb	1
Lepidogathis lutea Dalz	Herb	1
Amaranthaceae		
Alternanthera sessilis (L.) R.Br. ex DC.	Herb	1
Amaranthus viridis L.	Herb	1
Celosia argentea L.	Herb	2
Anacardiaceae		
Anacardium occidentale L.	Tree	1,2
Mangifera indica L.	Tree	1,2
Annonaceae		
Annona squamosa L.	Tree	1,2
Apocynaceae		
Allamanda cathartica L.	Shrub	2
Alstonia scholaris (L.) R.Br.	Tree	2
Hemidesmus indicus (L.) R.Br.	Twiner	1
Rauvolfia serpentina (L.) Benth. ex Kurz	Shrub	1
Asteraceae		
Chromolaena odorata (L.) R.M.King & H.Rob.	Herb	1,2
Emilia sonchifolia (L.) DC. ex Wight	Herb	1
Senecio bombayensis L.	Herb	1
*Tricholepis glaberrima*DC	Herb	1
Tridax procumbens L.	Herb	2
Balsaminaceae		
Impatiens balsamina L.	Herb	1
Impatiens kleinii Wight & Arn.	Herb	1
Bixaceae		
Bixa orellana L.	Shrub	2
Cannabaceae		
Trema orientalis (L.) Blume	Tree	1,2
Casuarinaceae		
Casuarina eqisetifolia L.	Tree	2
Clusiaceae		
Garcinia indica Choiss.	Tree	2
Colchicaceae		
Gloriosa superba L.	Climber	1
Combretaceae		
Calycopteris floribunda (Roxb.) Lam.ex Poir	Shrub	1,2
Commelinaceae		
Commelina diffusa Burm.f.	Herb	2
Murdannia semiteres(Dalzell) Santapau	Herb	1,2
Cyperaceae		
Cyperus iria L.	Herb	2
Cyperus rotandus L.	Herb	2
Euphorbiaceae		
Macaranga peltata Roxb. Mueller	Tree	1,2
Ricinus communis L.	Shrub	2
Fabaceae		
Acacia auriculiformis A.Cunn. ex Benth.	Tree	1,2
Acacia mangium Willd.	Tree	1,2
Alysicarpus vaginalis (L.) DC.	Herb	1
Cassia fistula L.	Tree	1,2
Senna siamea (Lam.) Irwin et Barneby	Tree	2
Senna tora (L.) Roxb.	Herb	1,2
*Crotalaria filipes*Benth.	Herb	1
Crotalaria pallida L.	Herb	1
Delonix regia (Boj. ex Hook.) Raf.	Tree	2
Gliricidia sepium (Jacq.) Kunth ex Walp.	Tree	2
Leucaena leucocephala (Lam.) de Wit	Tree	1,2
Mimosa pudica L.	Herb	1,2
Fabaceae		
Peltophorum pterocarpum (DC.) K.Heyne	Tree	2
Pithocellobium dulce(Roxb.) Benth.	Tree	2
Pongamia pinnata (L.) Panigrahi	Tree	1
*Smithia conferta*Sm.	Herb	1,2
Stylosanthes hamata (L.) Taub.	Herb	1,2
Tamarindus indica L.	Tree	2
Gentianaceae		
Canscora diffusa (Vahl) R.Br. ex Roem. & Schult.	Herb	1,2
Lamiaceae		
Gmelina arborea Roxb.	Tree	2
Leucas aspera(Willd.) Link	Herb	2
Leguminosae		
Phanera purpurea (L.) Benth.	Tree	2
Linderniaceae		
Lindernia crustacea(L.) F. Muell.	Herb	1,2
Lythraceae		
Punica granatum L.	Tree	1
Malvaceae		
Bombax ceiba L.	Tree	2
Gossypium arboreum L.	Shrub	2
Meliaceae		
Azadirachta indica A.Juss.	Tree	2
Moraceae		
Artocarpus altilis (Parkinson) Fosberg	Tree	2
Artocarpus heterophyllus Lam.	Tree	1,2
Ficus hispida L.f.	Tree	1
Myrtaceae		
Psidium guajava L.	Tree	2
Syzygium cumini (L.) Skeels	Tree	2
Orobanchaceae		
Rhamphicarpa fistulosa (Hochst.) Benth.	Herb	1
Phyllanthaceae		
*Phyllanthus emblica*L.	Tree	2
Plantaginaceae		
Scoparia dulcis L.	Herb	2
Poaceae		
Cymbopogon citratus (DC.) Stapf	Herb	2
Cynodon dactylon (L.) Pers.	Herb	2
Dactyloctenium aegyptium (L.) Willd.	Herb	1
Digitaria ciliaris (Retz.) Koeler	Herb	1
Eleusine indica (L.) Gaertn.	Herb	1
Eragrostis uniloides (Retzius) Nees ex Steudel	Herb	1
Panicum notatum Hack	Herb	1
*Panicum*sp.	Herb	2
Pennisetum hohenackeri Hochst. ex Steud.	Herb	2
Pteridaceae		
Adiantum philippense L.	Herb	1
Cheilanthes micropteria Sw.	Herb	1
Pteris pellucida L.	Herb	2
Rhamnaceae		
Zizyphus mauritiana Lam.	Tree	1
Rutaceae		
Citrus limon (L.) Osbeck	Tree	1
Sapotaceae		
Manilkara zapota (L.) P.Royen	Tree	1,2
Mimusops elengi L.	Tree	2
Simaroubaceae		
Simarouba glauca DC.	Tree	2
Verbenaceae		
Lantana camara L.	Herb	1,2

Legends: 1=Site 1; 2=Site 2

DISCUSSION

The study revealed that the soil of both the mine dumps was acidic in nature with very low levels of plant macro and micro-nutrients. Similar observations were recorded earlier by Rodrigues (2000). Nutrient deficiency is a primary limiting factor for plant growth on mining impacted sites. Overburdened rejected dumps are known to be deficient in plant macronutrients (Sheoran *et al*.,2008 ;2010).

In this study a total of 19 AM fungal species belonging to 8 genera were recovered from the rhizosphere soils of 84 plant

Table 3: Per cent root colonization and spore density of AM fungi on the selected mine sites.

Family and Plant species	Colonization %		Spore density %	
	Site 1	Site 2	Site 1	Site 2
Acanthaceae				
Andrographis paniculata (Burm.f.)Nees	53.33±5.81	-	16.67±1.76	-
Lepidogathis lutea Dalz.	42.67±3.71	-	22.67±5.21	-
Amaranthaceae				
Alternanthera sessilis (L.) R.Br. ex DC.	55.00±10.41	-	30.33±2.91	-
Amaranthus viridis L.	45.00±7.64	-	31.67±2.73	-
Celosia argentea L.	-	64.00±2.52	-	19.67±1.45
Anacardiaceae				
Anacardium occidentale L.	86.67±6.96	80.00±1.15	168.33±3.53	299.33±5.81
Mangifera indica L.	85.00±2.89	69.33±3.48	49.67±8.97	20.33±4.18
Annonaceae				
Annona squamosa L.	36.67±3.33	64.33±3.48	41.33±7.75	81.33±9.24
Apocynaceae				
Allamanda cathartica L.	-	45.33±3.53	-	22.00±3.06
Alstonia scholaris (L.) R.Br.	-	56.67±4.63	-	108.67±3.48
Hemidesmus indicus (L.) R.Br.	56.67±4.67	-	25.00±3.00	-
Rauvolfia serpentina (L.) Benth. ex Kurz.	35.00±5.00	--	21.00±1.15	
Asteraceae				
Chromolaena odorata (L.) R.M.King & H.Rob.	76.67±4.41	29.33±2.91	14.33±4.48	45.67±1.45
Emilia sonchifolia (L.) DC. ex Wight	78.00±3.46	-	24.33±2.85	-
Senecio bombayensis L.	52.00±4.62	-	10.33±1.33	-
Tricholepis glaberrima DC.	45.33±4.67	-	11.00±2.08	-
Tridax procumbens L.		66.67±4.41	-	31.33±4.06
Balsaminaceae				
Impatiens balsamina L.	68.00±4.62	-	25.67±2.60	-
Impatiens kleinii Wight & Arn.	42.00±7.02		25.33±3.71	-
Bixaceae				
Bixa orellana L.	-	35.00±2.89	-	62.33±2.60
Cannabaceae				
Trema orientalis (L.) Blume	80.67±4.06	68.00±6.11	79.33±4.67	90.00±4.62
Casuarinaceae				
Casuarina equisetifolia L.	-	25.00±5.77	-	23.67±4.33
Clusiaceae				
Garcinia indica Choiss.	-	49.33±1.76	-	105.67±5.21
Colchicaceae				
Gloriosa superba L.	18.33±4.41	-	26.33±3.84	-
Combretaceae				
Calycopteris floribunda (Roxb.) Lam.ex Poir	16.65±6.01	53.33±12.02	26.33±3.84	59.00±3.46
Commelinaceae				
Commelina diffusa Burm.f.	-	33.33±6.01	-	22.67±2.40
Murdannia semiteres (Dalzell) Santapau	23.33±8.33	34.67±2.40	16.00±2.52	24.33±4.48
Cyperaceae				
*Cyperus iria*L.	-	63.33±7.26	-	31.00±1.53
Cyperus rotandus L.	--	43.33±8.82		25.00±3.51
Euphorbiaceae				
Macaranga peltata Roxb. Mueller	55.33±3.53	51.00±4.93	68.33±4.91	16.67±4.91
Ricinus communis L.	-	62.67±1.45	-	63.00±8.62
Fabaceae				
Acacia auriculiformis A.Cunn. ex Benth.	31.67±6.07	30.00±4.16	44.00±2.65	22.67±2.67
Acacia mangium Willd.	33.33±4.41	26.67±9.28	18.33±3.71	48.33±8.35
Alysicarpus vaginalis (L.) DC.	36.33±3.28	-	19.67±3.28	-
Casia fistula L.	72.00±3.06	78.33±4.41	54.33±4.10	76.67±4.98
Senna siamea (Lam.) Irwin et Barneby	-	31.00±4.16	-	41.67±2.40
Senna tora (L.) Roxb.	66.67±2.91	51.00±3.61	96.33±3.84	80.33±3.93
*Crotalaria filipes*Benth.	35.00±2.89	-	17.00±3.21	-
Crotalaria pallida L.	35.33±6.36	--	13.00±1.53	
Delonix regia (Boj. ex Hook.) Raf.	-	58.33±13.02	-	46.00±11.59
Gliricidia sepium (Jacq.) Kunth ex Walp.	-	40.00±8.66	-	65.67±11.57
Leucaena leucocephala (Lam.) de Wit	31.67±8.82	65.00±7.64	25.33±4.48	34.33±6.77
Mimosa pudica L.	46.67±7.26	28.67±2.03	34.67±8.74	24.00±4.00

Cont.....

Family and Plant species	Colonization %		Spore density %	
	Site 1	Site 2	Site 1	Site 2
Fabaceae				
Peltophorum pterocarpum (DC.) K.Heyne	-	55.00±2.89	-	41.00±8.74
Pithocellobium dulce (Roxb.) Benth.	-	54.67±2.40	-	65.33±4.06
Pongamia pinnata (L.) Panigrahi	31.67±1.76	-	57.67±3.84	-
Smithia conferta Sm.	60.00±10.41	36.67±9.28	15.00±3.46	59.33±3.18
Stylosanthes hamata (L.) Taub.	46.00±4.00	39.67±0.88	35.00±4.51	36.67±5.70
Tamrindus indica L.	-	41.33±4.37	-	78.33±2.91
Gentianaceae				
Canscora diffusa (Vahl) R.Br. ex Roem. & Schult.	71.33±3.53	60.00±7.64	50.33±3.76	34.00±5.29
Lamiaceae				
Gmelina arborea Roxb.	-	61.67±4.41	-	52.00±5.13
Leucas aspera (Willd.) Link.	-	47.00±4.36	-	16.67±4.91
Leguminosae				
Phanera purpurea (L.) Benth.	-	39.67±2.03	-	33.67±3.18
Linderniaceae				
Lindernia crustacea (L.) F. Muell.	43.33±13.02	30.00±7.64	10.00±1.53	26.00±6.43
Lythraceae				
Punica granatum L.	18.33±1.67	-	12.33±2.85	-
Malvaceae				
Bombax ceiba L.	-	61.33±1.86	-	36.67±2.60
Gossypium arboreum L.	-	68.33±10.93	-	25.67±3.38
Meliaceae				
Azadirachta indica A.Juss.	-	58.33±3.18	-	85.67±3.38
Moraceae				
Artocarpus alitis (Parkinson) Fosberg	-	63.33±9.28	-	33.00±11.59
Artocarpus heterophyllus Lam.	63.33±7.26	42.33±2.85	69.33±5.36	15.67±4.91
*Ficus hispida*L.f.	53.33±6.01	-	41.00±8.08	-
Myrtaceae				
Psidium guajava L.	-	48.67±1.76	-	24.00±4.62
Sygzgium cumini (L.) Skeels	-	38.00±4.73	-	50.33±6.69
Orobanchaceae				
Rhamphicarpa fistulosa (Hochst.) Benth.	23.33±4.41	-	14.67±3.28	-
Phyllanthaceae				
Phyllanthus emblica L.	-	43.67±1.86	-	40.67±4.91
Plantaginaceae				
Scoparia dulcis L.	-	38.33±9.28	-	21.33±2.91
Poaceae				
Cymbopogon citratus (DC.) Stapf	-	73.33±4.41	-	52.00±8.89
Cynodon dactylon (L.) Pers.	-	79.33±0.67	-	20.67±3.28
Dactyloctenium aegyptium (L.) Willd.	56.67±9.28	-	31.67±3.67	-
Digitaria ciliaris (Retz.) Koeler	60.00±10.41	-	30.00±1.53	-
Eleusine indica (L.) Gaertn.	31.67±6.01	-	13.00±4.36	-
Eragrostis uniloides (Retzius) Nees ex Steudel	35.00±5.00	-	21.00±3.61	-
Panicum notatum Hack	48.33±10.14	-	12.33±2.85	-
Panicum sp.	-	46.67±3.53	-	41.00±4.36
Pennisetum hohenackeri Hochst. ex Steud.	-	71.67±7.26	-	31.33±7.06
Pteridaceae				
Adiantum philippense L.	11.65±1.67	-	8.33±0.88	-
Cheilanthes micropteria Sw.	26.67±2.91	-	20.00±1.15	-
Pteris pellucida L.	-	60.00±7.64	-	8.67±1.20
Rhamnaceae				
Zizyphus mauritiana Lam.	63.33±8.82	-	19.33±6.44	-
Rutaceae				
Citrus limon (L.) Osbeck	23.35±7.26	-	14.66±3.28	-
Sapotaceae				
Manilkara zapota (L.) P.Royen	28.30±6.01	46.67±2.33	26.00±6.56	36.67±2.03
Mimusops elengi L.	-	38.00±3.06	-	55.67±3.76
Simaroubaceae				
Simarouba glauca DC.	-	58.00±5.69	-	96.67±6.89
Verbenaceae				
Lantana camara L.	76.00±5.29	65.33±3.71	304.00±3.21	72.00±6.08
Note: All values are mean of three readings; ± = Standard error.				

Table 4: Relative Abundance (RA) and Isolation frequency (IF) of AM fungi on the selected mine sites.

AM fungal species	RA %		IF%	
	Site 1	Site 2	Site 1	Site 2
Acaulospora delicata Walker, Pfeiff. & Bloss	4.53	5.01	15.65	17.86
Acaulospora dilatata Morton	1.82	1.21	10.20	5.95
Acaulospora myriocarpa Spain, Sieverd. & Schenck,	1.16	3.03	4.08	8.33
Acaulospora rehmii Sieverd. & Toro	4.97	7.03	16.33	20.24
Acaulospora scrobiculata Trappe	7.26	6.85	12.93	29.76
Acaulospora undulata Sieverd.	5.28	2.39	13.61	8.33
Funneliformis geosporum (Nicolson & Gerd.) Walker & Schüßler	0.38	0.59	2.04	2.98
Gigaspora albida Schenck & Sm.	29.72	21.99	56.46	41.07
Gigaspora decipiens Hall & Abbott	10.43	2.06	19.73	3.57
Gigaspora gigantea (Nicolson & Gerd.) Gerd. & Trappe	-	3.52	-	7.14
Gigaspora margarita Becker & Hall	3.48	1.80	8.16	5.36
Glomus macrocarpum Tul. & Tul.	0.36	0.63	2.04	4.17
Racocetra gregaria (Schenck & Nicolson) Oehl, Souza & Sieverd.	3.08	6.68	10.88	8.93
Rhizophagus fasciculatus (Thaxt.) Gerd. & Trappe	0.96	-	3.40	-
Sclerocystis rubiformis Gerd. & Trappe	0.15	0.13	1.36	2.38
Sclerocystis sinuosa Gerd. & Bakshi	0.25	-	2.72	-
Sclerocystis taiwanensis Wu & Chen	-	0.06	-	1.19
Scutellospora calospora(Nicolson & Gerd.) Walker & Sanders	4.02	1.94	10.88	3.57
Scutellospora heterogama (Nicolson &Gerd.) Walker & Sanders	21.44	35.09	25.85	42.86

species belonging to 36 families. Mycorrhizal symbiosis plays a crucial role in survival and nutrient uptake of plants especially in P deficient derelict soils (Khan, 2005). However, very low P availability is responsible to inhibit AM colonization (Tinker, 1975; Bolan, 1991; de Miranda and Harris, 1994).

Acaulospora was the dominant genus on both the study sites. The acidic nature of the reject dumps may explain the dominance of the genus *Acaulospora.* According to Giovannetti *et al.*, (2010) the genus *Acaulospora* is predominant in acidic soils. However, this is contradictory to the results in earlier studies (Jasper *et al*., 1988; Sastry and Johri, 1999; Sharma *et al*., 2009; Kullu and Bahera, 2012) who recorded *Glomus* to be the dominant genus on the mine spoil dump. However, our study revealed that in terms of RA and IF, *Gi. albida* and *Sc. heterogama* were dominant species on site 1 and site 2, respectively. This dominance may be due to change in host's nutritional demands in the developmental stages as AM species that colonise the host in early stages become minor and are replaced by previously undetected species (Hart *et al*., 2001; Husband *et al*., 2002).

The present study also revealed a significant correlation between spore density and root colonization. This may be due to edaphic or climatic factors, root morphology of host plant, and germination of AM propagules (Beyene *et al*., 2016; Zangaro *et al*.,2005). Similarly, RA and IF showed significant positive correlation at both the sites indicating that AM species producing more spores usually had a wider distribution, while species with small geographic ranges usually produced fewer spores as reported earlier (Zhao and Zhao, 2007).

Table 5: Diversity measurements of AM fungal communities at the two mine sites.

Ecological parameters	Values	
	Site 1	Site 2
Shannon-Weiner index (H)	2.16	2.07
Simpsons index of dominance (D)	0.84	0.81
Evenness (E)	0.76	0.73

It is observed that the Shannon Wiener diversity (H) was higher at site 1. The distribution of AM species was uniform at both the study sites. According to Bever *et al*., (1996) the pattern of unevenness in spore density is due to differences in sporulation pattern of AM species.

CONCLUSION

From a restoration perspective, it is very much essential to understand the factors leading to stabilization of mine wastelands and conditions under which plants establish to become stable plant communities. In the present study, an appreciable amount of AM fungal diversity has been recorded in plants growing on stabilized iron ore mine dumps. However, further studies are required to understand seasonal variations and sporulation patterns of AM fungi at different phenology of host plants.

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