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Arbuscular mycorrhizal and dark septate endophytic fungal associations in four ginger species of Manipur, North Eastern India

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Population and species richness of Arbuscular Mycorrhizal (AM) fungi in rhizosphere soils and morphology, colonization patterns of AMF and Dark Septate Endophyte (DSE) fungal structures in the roots of four important ginger species (*Alpinia allughas*, *Cucurma caesia*, *Cucurma longa* and *Hedychium coronarium*) grown in Manipur, Northeastern (NE) India were examined. Maximum and minimum spore density of AM fungi were recorded in the 100 g rhizosphere soils of *C. caesia* (310 spores) and *A. allughas* (64 spores), respectively. A total of 23 AM fungal spore morphotypes belonging to seven different genera i.e. *Acaulospora, Claroideoglomus, Funneliformis, Glomus, Rhizophagus, Sclerocystis* and *Septoglomus* were isolated and identified from the rhizosphere and trap culture soils of studied ginger species. *Funneliformis geosporus* revealed the highest percentage of relative abundance and isolation frequency. The distribution and species richness of AM fungal community was dominated by the members belonging to Order Glomerales which was represented by 14 species. The examined root fragments of four ginger species had both AM and DSE fungal colonization and revealed intermediate- type (I4) of AM morphology. Total root length with AM colonization was highest in *H. coronarium* (71.3%). Pearson's correlation analysis showed significant positive and negative interactions with some of the soil properties *viz*. pH with total AM colonization and %OC, N and K contents with AM spore density, respectively.

Key words: Gingers, AM Fungi, Dark septate endophyte, colonization patterns

INTRODUCTION

Zingiberaceae, a well known family, is explored worldwide for their high medicinal properties and versatile nature. Manipur, one of the state of North Eastern (NE) India falls within the Indo Burma hot spot region and had many wild and domesticated gingers belonging to 88 species under 19 genera (Sharma *et al.* 2011), among which *Alpinia allughas* (Retz.) Rosc., *Cucurma caesia* Roxb., *Cucurma longa* Linn. and *Hedychium coronarium* Konig. are most abundantly found in the hilly and valley regions of Manipur, locally known as Pullei, Yaimu, Yaingang and Takhelei, respectively. The aqueous extract of leaves and fleshy rhizomes of naturally growing *A. allughas* are used in the treatment of several health issues like rheumatoid inflammations, irregular menstruation, jaundice, gastric ulcers, cough, asthma, diabetes and fevers etc. (Sethi *et al.* 2015). Similarly, Mukunthan *et al.* (2017), Kocaadam and [a]anlier (2015) and Panigrahy *et al.* (2018) also documented the medicinal properties of black zedoary (*C. caesia*), turmeric (*C. longa*) and white butterfly ginger lily (*H. coronarium*) rhizomes. Arbuscular mycorrhizal fungi (AMF) are the major components of the soil biota in natural and agricultural ecosystems and form symbiotic associations with roots of over 90% terrestrial plant species including rhizomatous ones (Uma *et al.* 2010). The AM fungi improve the plant growth and productivity by enhancing the uptake of immobile mineral nutrient such as phosphorus (P) from the soil and providing the tolerance for abiotic and biotic stresses. The occurrence of AM fungi in many plants of different taxonomic groups has been reported. However, the mycorrhizal status of about 76% of monocot families is reported till now (Uma *et al.* 2010). Therefore, examining the mycorrhizal status in majority of plant species are needed to understand the extent of root colonizing endorhizal fungi in different habitats. In addition to AM, plant roots

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are also associated with Dark Septate Endophytes (DSE) which are characterized by presence of darkly pigmented septate hyphae and compact microsclerotial structures. A meta-analysis by Newsham (2011) suggest that the application of DSE fungi usually improve the plant growth performances under glasshouse controlled conditions. However, information on DSE fungal association in tropical and subtropical plant roots, particularly to that of NE India, is limited compared to temperate ones (Pandey *et al*. 2016).

Studies on the prevalence of AMF in rhizosphere soil and colonization in roots of some Zingiberaceae members has been reported earlier (Uma *et al*., 2010). Colonization of common edible ginger (*Z. officinale*) rhizomes and scale leaves by AM fungi has been reported for the first time in Hawaii and Fiji islands. Likewise, Uma *et al*. (2010), Songachan and Kayang (2011), Dutta and Neog (2015), and Halder *et al*. (2015) also observed the prevalence of AM fungi in *Alpinia allughas* (formerly *Alpinia nigra*), *Cucurma caesia*, *Cucurma longa* and *Hedychium coronarium* from different tropical and temperate ecosystems. In contrast, the association of DSE fungi in roots of *A. allughas* and *C. caesia* has not been reported till date. Furthermore, no information is available on the AM and DSE associations with the rhizomes of different ginger species from NE India which is the hot spot region of biodiversity. Hence, the present study has been carried out to determine the diversity of AM fungi in the rhizosphere soils and to assess the AM morphology and root colonization intensities by AM and DSE fungal structures in four ginger species grown under subtropical areas of Manipur, NE India.

MATERIALS AND METHODS

Study sites and Materials

The present work was conducted with four ginger species, viz., *A. allughas* and *H.coronarium* grown naturally under Langol forest extension of Imphal West district (location: 24°51¹45.0°NLatitude; 93°53¹15.7°E Longitude) and *C. caesia* and *C.longa* from gentle slope of hillock in Senapati district (location: 25°16¹43.3 N Latitude; 94°01¹12.1°E Longitude), Manipur. The mean annual temperature, relative humidity and total annual rainfall of both the study sites ranged from 3.4°C to34.4°C, 76% to 92%, 1454 mm to 1535mm, respectively. The climate of both sites fall under the subtropical humid type.

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Sample collection

The root and soil samples were collected by digging 0–20 cm soil depth around the root zones of five randomly selected plants (6 months old) belonging to each ginger species(*A. allughas*, *C. caesia*, *C. longa* and *H. coronarium*) during October, 2017. Approximately 1kg of rhizosphere soil was collected from the individual plant of the selected gingers, kept in a polythene bag separately, labeled and brought to the laboratory. Soils of each ginger species were air dried under shade at room temperature (28 ºC) and mixed together. The composite soils belonging to each species were divided into two halves; one-half was stored at 4 ºC for enumeration of AM fungal spores and other half was used for establishing trap cultures and analyzing the physico-chemical characteristics. The roots were gently washed with water to make them free from soil and were fixed in FAA solution until further processing.

Determination of soil properties

The texture of the soil sample was assessed by Bouyocos hydrometer method (Allen *et al*. 1974) whereas the pH and electrical conductivity (EC) of the soil were determined at room temperature from aqueous suspension of soil-water (1:1, v: v) using the digital pH and conductivity meter, respectively and percent organic carbon (%OC) was determined. Soil total nitrogen (N), available phosphorus (P) and exchangeable potassium (K) were evaluated after extraction with ammonium acetate (Jackson, 1971). All the soil properties were assessed in triplicate for each ginger species.

Extraction and identification of AMF spores

The AM fungal spores were extracted by wet sieving and decanting method (Gerdeman and Nicolson, 1963) in which 100g of soil sample (in triplicate) belonging to each ginger species was dispersed in 1L of water and the suspension was decanted through a series of 710 to 37 ìm sieve s series. After washing into beakers, the residues were filtered through girdled filter papers. Each

filter paper was then spread on glass plates and observed under the light microscope at x40 magnification. All the AM spores were counted and transferred to the glass slide using a wet needle (Schenck and Perez, 1990) and mounted in polyvinyl alcohol-Lacto glycerol (PVLG) with or without Melzer's reagent. The AMF spores were identified on the morphological basis, and sub-cellular characters were compared with the culture database established by INVAM (http://invam.cag.wvu.edu/) and Schüssler's web site (http://www.lrz-muenchen.de/~schuessler/amphylo/amphylo_species.html). The AM fungal spore density, species richness, relative abundance and isolation frequency were calculated according to Dandan and Zhiwei (2007).

Assessment of AM and DSE fungal colonization

Fifteen root segments (1cm length) of each ginger species were cut after washing with distilled water, processed for clearing with 2.5% KOH at 90 ºC for about 90–120 min in a water bath, acidified with 5N HCl for 15 min and stained in Trypan blue-lactoglycerol (0.05%) overnight, then mounted on glass slides in lactoglycerol and examined for AM and DSE fungal structures in stereoscopic compound microscope (Nikon Eclipse Ni- U, Japan). The percentage of root length colonization by different fungal structures was estimated according to the magnified intersection method (McGonigle *et al*. 1990). Further, AM morphology was classified as Intermediate-type based on the presence of inter- or intracellular nature of fungal structures within the root cortical cells as described by Dickson (2004).

Establishment of Trap Culture

The composite soil samples along with the root fragments of four ginger species were mixed with sterilized coarse sand (1:1 v/v) and filled in triplicate earthen pots(2kg/pot). Trap culture pots were sown with maize (*Zea mays*) seeds as host plant and kept in greenhouse conditions with temperature range between 20–26°C and relative humidity from 77 to 90%, and watered every alternate day. After 120 days of culture initiation, the developed spores of AM fungi were extracted and identified as stated above.

Statistical analysis

One way analysis of variance (ANOVA) was performed to assess the differences in soil properties, AMF spore density, root colonizing AM and DSE fungal structures in four studied ginger species (SPSS version 20, SPSS Inc., Chicago, Illinois). Pearson's correlation was carried out to study the relationship between soil properties and endorhizal colonization structures. Standard errors of means were calculated.

RESULTS AND DISCUSSION

Soil physico-chemical properties

The soil samples collected from gingers were sandy clayey loam in texture and slightly acidic in nature. Maximum concentrations of EC, %OC, total N and exchangeable K were found in *A. allughas* soil, whereas that of available P was found to be higher in *C. longa*. However, all the soil properties were significantly (P>0.001) different among the studies ginger species (Table 1).

Spore density and distribution of AM fungi

The AM fungal spore density observed in the examined air-dried soils of *A. allughas*(64 spores 100 g^{-1}), *C. caesia* (309 spores 100 g^{-1}), *C. longa* (152 spores 100 g^{-1}) and *H. coronarium* (136 spores 100 g^{-1}) are comparatively higher (Fig.1) to that reported in *C. caesia, C. longa* and *H. coronarium* and in other spiral gingers (10 to 22 spores 100 g^{-1} soil) cultivated in natural and agricultural fields of South India (Uma *et al*. 2010). The spore population of AM fungi exhibited significant variation among different ginger rhizospheres ($F_{3,56}$ = 565.31; P< 0.001). The AM spore density in different crop soils were found to be influenced by the soil properties such as soil pH and nutrient availability therein (Surendirakumar *et al.,* 2019).However, it has been suggested that variations in density and diversity of AMF in different crop field soils might be due the influence of host plant species, micro-environmental conditions of the study site and fungal growth factors.

Altogether, 23 AM fungal morphotypes belonging to seven different genera, i.e. *Acaulospora, Claroideoglomus, Funneliformis, Glomus, Rhizophagus,Sclerocystis* and *Septoglomus* were

Table 1: Rhizosphere soil characteristics of different ginger species

Ginger species	Soil variables[1#]					
	pH	EC (dSm^{-1})	OC (%)	N ($Kg\ ha^{-1}$)	P ($Kg\ ha^{-1}$)	K ($Kg\ ha^{-1}$)
A. allughas	5.6±0.03a	0.33±0.02c	2.4±0.01c	113.7±1.50c	76.3±1.83a	226.6±1.95c
C. caesia	5.8±0.02b	0.25±0.02b	1.8±0.04a	94.9±1.28b	80.8±1.04b	190.8±2.28a
C. longa	5.9±0.03c	0.22±0.01a	1.9±0.02a	97.8±0.80b	84.9±2.68c	187.1±2.97a
H. coronarium	6.1±0.02d	0.30±0.01c	2.1±0.02b	90.0±2.30a	77.0±2.30a	210.0±1.68b

[1]Soil pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (N), available phosphorus (P) and exchangeable potassium (K), respectively.
Means ± SE in a column followed by same letter(s) are not significantly different ($P > 0.05$) according to DMRT.

Table 2: Percentage Relative abundance (RA) and isolation frequency (IF) of AM fungal species in ginger species

AMF species	RA (%) Ginger species				
	A. allughas	*C. caesia*	*C. longa*	*H. coronarium*	IF (%)
Acaulospora bireticulata F.M. Rothwell and Trappe	2.94	–	5.37	–	12.50
Acaulospora mellea Spain and N.C. Schenck	–	–	–	5.92	12.50
Acaulospora rehmii Sieverd and S. Toro	–	–	–	3.55	12.50
Acaulospora spinosa C. Walker and Trappe	4.90	8.06	10.07	–	25.00
Acaulospora sp.1	1.96	–	–	–	4.17
Acaulospora sp.2	0.98	–	–	–	4.17
Acaulospora sp.3	–	–	–	–	4.17
Acaulospora sp.4	–	–	4.03	–	8.33
Acaulospora sp.5	–	–	–	0.59	4.17
Claroideoglomus etunicatum C. Walker and Schuessler	–	–	–	15.38	25.00
Funneliformis geosporus C. Walker and Schuessler	29.41	50.00	35.57	15.98	75.00
Funneliformis mosseae C. Walker and Schuessler	24.51	37.10	13.42	–	54.17
Glomus magnicaule I.R. Hall	14.71	–	18.79	12.43	41.67
Glomus microcarpum Tul and C. Tul.	–	–	–	20.71	25.00
Glomus multicaule Gerd. and B.K. Bakshi	–	–	12.75	–	8.33
Glomus sp.1	2.94	–	–	–	4.17
Glomus sp.2	–	4.84	–	–	4.17
Glomus sp.3	–	–	–	1.18	4.17
Glomus sp.4	–	–	–	1.78	8.33
Rhizophagus intraradices C. Walker and Schuessler	–	–	–	5.33	12.50
Sclerocystis rubiformis Gerd. and Trappe	17.65	–	–	7.69	25.00
Septoglomus constrictum Sieverd, G.A. Silva and Oehl	–	–	–	7.10	12.50
Septoglomus viscosum C. Walker, D. Redecker, D. Stille and Schuessler	–	–	–	2.37	12.50
Total= 23	100	100	100	100	
Species richness	9	4	7	13	

– indicate absence of a particular AMF species

Table 3: Extent of arbuscular mycorrhizal (AM) and dark septate endophyte (DSE) fungal colonization in ginger species

Plant species	AM colonization (%)[†#]				DSE colonization (%)[‡#]			
	%RLH	%RLHC	%RLA	%RLV	%RLTC	%RLDH	%RLMI	%RLTDC
A. allughas	34.3±1.78a	7.6±0.87a	11.9±0.74b	4.6±0.61b	58.4 ±1.36b	3.9±0.96a	4.2 ±0.92b	8.1±1.00b
C. caesia	33.2±1.52a	9.2±1.04a	7.7±0.86a	2.5±0.48a	52.7±1.34a	4.4±0.83a	2.3±0.52a	6.7±0.92b
C. longa	40.2±1.11b	14.2±0.89b	6.8.±0.65a	3.9±0.84ab	65.2±1.12c	6.7±1.02b	1.9±0.65a	8.6±1.01b
H. coronarium	41.5±1.30b	8.4±0.53a	8.0±0.46a	13.4± 0.53c	71.3±1.72c	2.5±0.86a	1.6±0.52a	4.1±0.98a

[†]%RLH, %RLHC, %RLA, %RLV and %RLTC -indicate percentage root length with hyphae, hyphal coils, arbuscules, vesicles and total AM colonization, respectively.
[‡]% RLDH, %RLMI and %RLDTC -indicates root length with dark septate hyphae, microsclerotia and total root DSE colonization, respectively.
Means ± SE in a column followed by same letter(s) are not significantly different ($P > 0.05$) according to DMRT.

isolated from both the field and trap culture soils of selected ginger species (Table 2, Fig. 2). However, Uma *et al*. (2010) recorded only 18 AMF species from the soils of other Zingiberaceae members grown in Kerala, India. Such variation in the diversity of AMF species have been previously reported in a variety of habitats, land use types and agroecosystems (Opik *et al*. 2006; Pandey *et al*. 2016; Surendirakumar *et al*. 2019). In this study, the maximum AMF species (13) was recorded in the rhizosphere soil of *H. coronarium*. Among the isolated AM morphotypes, the genus *Acaulospora* was represented by nine species, followed by *Glomus* (7species) and *Funneliformis* and *Septoglomus* with 2 species each. Whereas, in case of *Rhizophagus* and *Sclerocystis* only a single species was isolated from studied gingers soils. Of these, *Funneliformis geosporus* was recovered from all the four test plant species with highest percentages of RA and IF (Table 2). Spore morphotypes of *Acaulospora* sp.1, *Acaulospora* sp.2 and *Glomus* sp.1 were found specifically in the *A. allughas* soil. *Glomus* sp.2 was exclusively found in *C. caesia* rhizosphere. While, *Acaulospora* sp.3 and 4 and *Glomus multicaule* were specific to *C. longa* soil. Moreover, *Acaulospora mellea, Acaulospora rehmii, Acaulospora.* sp. 5*, Claroideoglomus etunicatum, Glomus* sp. 3and4, *Rhizophagus intraradices* and *Septoglomus viscosum* were isolated exclusively from the *H. coronarium* soils. Hence, the present findings revealed that the majority of the identified AMF species belongs to Order Glomerales. This suggests that the species under Glomerales can be considered as generalists that produce large number of spores within short period and show the ability to adapt wide range of plant communities in different ecosystems (Pandey *et al*. 2016). Similarly, Uma *et al*. (2010) also recorded 14 AM fungal species belonging to Order Glomerales and only 6species from other AM taxonomic groups in gingers rhizosphere.

AM morphology and extent of AM and DSE fungal root colonization

All the examined root fragments of four ginger species had dual associations of both AM and DSE fungi (Table 3, Fig. 3) and revealed Intermediate× type (I4) AM morphology with intercellular hyphae, intracellular hyphal coils, arbuscules and vesicles. Likewise, Uma *et al*. (2010) also observed that roots of 80% of the ginger and spiral ginger species have Intermediate- type AM. In contrast, Halder *et al*. (2015) reported *Arum*- type AM morphology in *A. allughas* grown in natural field of Chittagong, Bangladesh. Uma *et al*. (2010) and Songachan

Table 4: Pearson's correlation between AM and DSE fungal variables and soil factors (n = 20).

Variables		AM†						DSE‡		
		SPN	%RLH	%RLHC	%RLA	%RLV	%RLTC	%RLDH	%RLMI	%RLDTC
Soil[1]	pH	0.130	0.479*	0.206	–0.426	0.673**	0.618**	–0.055	–0.567**	–0.520*
	EC	–0.420	–0.117	–0.429	0.220	0.346	0.019	–0.482*	0.291	–0.155
	%OC	–0.761**	–0.078	–0.474*	0.603**	0.221	0.084	–0.472*	0.459*	0.045
	N	–0.533*	–0.247	–0.251	0.594**	–0.400	–0.271	–0.108	0.568**	0.447*
	P	0.338	0.176	0.421	–0.263	–0.433	–0.036	0.658**	–0.451*	0.297
	K	–0.713**	–0.038	–0.512*	0.648**	0.305	0.155	–0.577**	0.307	–0.118
AM	SPN		–0.201	0.092	–0.414	–0.352	–0.492*	0.222	–0.211	–0.088
	%RLH			–0.199	–0.253	0.361	0.673**	0.067	–0.425	–0.388
	%RLHC				–0.220	–0.106	0.221	0.449*	–0.143	0.353
	%RLA					0.006	0.032	–0.443	0.249	0.074
	%RLV						0.753**	–0.467*	–0.176	–0.566**
	%RLTC							–0.144	–0.340	–0.355
DSE	%RLDH								–0.190	0.704**
	%RLMI									0.388

[1]Soil pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (N), available phosphorus (P) and exchangeable potassium (K), respectively.

†%RLH, %RLHC, %RLA, %RLV and %RLTC -indicate percentage root length with hyphae, hyphal coils, arbuscules, vesicles and total AM colonization, respectively.

‡% RLDH, %RLMI and %RLDTC -indicates root length with dark septate hyphae, microsclerotia and total root DSE colonization, respectively.

Signficance at **P* < 0.05 and ***P* < 0.01.

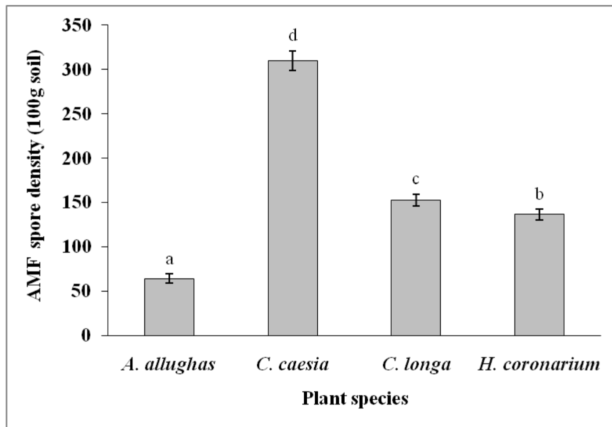

Fig. 1: Spore density of AM fungi in soils of selected plant species

and Kayang (2011) also observed *Arum*- type morphology in *C. longa* and *H. coronarium* roots from Kerala and Meghalaya states of India, respectively. However, the ability of AMF to develop different morphological types in the same species of plant genera is probably due to the influence of growth rates of host plant species, colonizing AMF species and the environmental conditions prevailed therein, such as light intensity, temperature and soil moisture etc.

The roots of the studied gingers were colonized by AMF, which reveal the ubiquity of mycorrhizal association in tropical and sub-tropical

Fig. 2: AMF spores isolated from rhizosphere soils of studied ginger species. a) *Acaulospora mellea*, b) *Acaulospora rehmii*, c) *Acaulospora spinosa*, d) *Claroideoglomus etunicatum*, e) *Funneliformis geosporus*, f) *Funneliformis mosseae*, g) *Glomus magnicaule*, h) *Glomus microcarpum*, i) *Glomus multicaule*, j) *Rhizophagus intraradices*, k) *Sclerocystis rubiformis*, l) *Septoglomus viscosum* and m) *Septoglomus constrictum.* Scale bars = 20 μm.

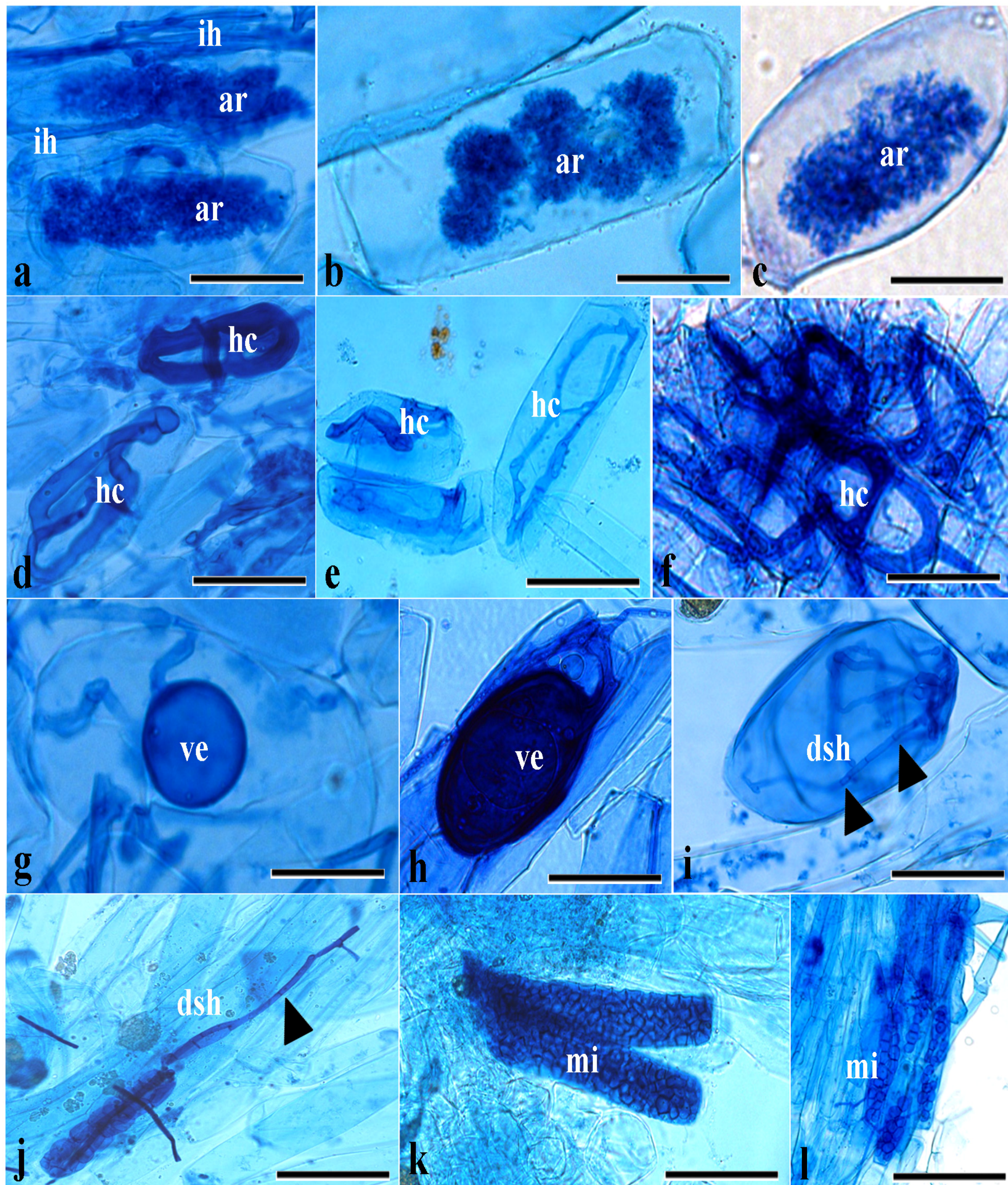

Fig. 3: Arbuscular mycorrhizal (AM) and dark septate endophyte (DSE) fungal colonization. Arbuscules (a-c) in *A. allughas*, *C. caesia* and *H. coronarium* respectively; Hyphal coil (d-f) in *A. allughas*, *C. caesia* and *H. coronarium* respectively; Vesicles in *A. allughas* (g) and *H. coronarium* (h); DSE hyphae in *C. caesia* and *C. longa*(i); microsclerotia in *C. caesia* (k) and *H. coronarium* (l); ar-arbuscule, hc- hyphal coil, ve- vesicle, dsh- DSE fungal hyphae, mi- microsclerotia. (Scale Bars: 40-60µm).

agroecosystems. Nevertheless, the incidence of percentage root length with total AM colonization (%RLTC) ranged from 52.7 to 71.3% in the present study, which was in accordance with the findings of Uma *et al.* (2010) and Dutta and Neog (2015) who observed 54 to 76% colonization in roots of 40 Zingiberaceae members. However, the %RLTC in *A. allughas* (58.4%), *C.caesia* (52.7%) and *C.longa* (65.2), in this study, was comparatively lower to other findings (Uma *et al.* 2010; Halder *et al.* 2015). Whereas, roots of *H. coronarium* (71.3%) had higher AM colonization to those reported for

the same species from NE India (Songachan and Kayang, 2011) which suggest that the intensity of AM colonization could be influenced by specific habitat conditions and the soil factors including phosphorus availability (Smith and Read, 2008).Our findings revealed the significant variations among studied ginger species and their percentage root length colonization with AM structures i.e. hyphae (%RLH) ($F_{3, 56}$ = 8.24; *P*< 0.001), hyphal coils (%RLHC) ($F_{3, 56}$ = 12.25; *P*< 0.001), arbuscules (%RLA) ($F_{3, 56}$ = 10.51; *P*< 0.001), vesicles (%RLV) ($F_{3, 56}$ = 61.09; *P*< 0.001) and %RLTC($F_{3, 56}$ = 22.56; *P*< 0.001).

The examined ginger roots were also colonized by different DSE fungal structures, viz., melanized septate hyphae and microsclerotia (Fig. 3), though their hyphae and microsclerotia occurred in low percentages (Table 3).In this study, the extent of percentage of total root length colonization by DSE fungi (%RLDTC) varied from 4.1 to 8.6% which is lower with that of 22% in other gingers and spiral gingers reported by Uma *et al*. (2010). To our knowledge, we report DSE association for the first time in *A. allughas* and *C. caesia* (Table 3). However, Uma *et al*. (2010) failed to find colonization by DSE fungi in roots of *C. caesia* and *H. coronarium* plants. Significant variations were observed between the extent of root colonization with DSE fungal structures in 4 examined gingers. Usually the DSE fungi are mostly found in cold and nutrient stressed ecosystems where many AMF species are unable to proliferate due to adverse conditions (Mandyam and Jumponnen, 2005). Like AMF symbiosis, DSE fungi also influence the host plants which vary from mutualism to parasitism depending on the plant and fungal genotype and environmental conditions (Newsham, 2011).

Soil properties are known to affect AMF functioning and colonization levels (Smith and Read, 2008). The present findings showed that AMF spore density was significantly and negatively (*r*= –0.761; *P*<0.01) correlated with % OC of studied ginger soils (Table 4). Singh *et al*. (2003) also found a similar relationship among these variables from the soil of Jhum fallow in NE India. Further, AMF spore density was significantly and negatively correlated with %RLTC(*r*= –0.492; *P*<0.01) which is in accordance with the finding of Surendirakumar *et al*. (2019). This indicates clearly that the spore density of AM fungi community does not reflect exactly their root colonizing ability because of the possible existence of some non-sporulating AMF species. Moreover, soil pH was significantly and positively correlated with %RLV (*r*= 0.673; *P*<0.01) and %RLTC (*r*= 0.618; *P*<0.01) in the present study, which contradicts earlier reports where a negative correlation has been reported for these variables (Muthukumar and Muthuraja, 2016). Smith and Read (2008) also suggested that soil pH can influence the quantity of AM fungal spores in the soil, hyphal growth and root colonization frequency. Lingfei *et al*. (2005) reported that there was no significant correlation between total AM and DSE fungal variable in grasslands of China, which is similar to our results (*r*= –0.355; *P*<0.05).

In conclusion, the occurrence of both AM and DSE fungi in the examined gingers indicate the dynamic nature of diverse root-colonizing fungal communities in this region of India. Variations in edapho-climatic factors and the microclimatic environments might be responsible for differences in AM and DSE fungal colonization in different host gingers and the density of AMF spores in respective rhizosphere soils. Experimental studies involving different AM and DSE fungi are necessary to ascertain their ability to promote plant growth and their suitability for sustainable management of ginger plantations in the future.

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