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Status of endogenous endomycorrhizal fungi associated with cowpea (*Vigna unguiculata* L.) in the Sudano-Sahelian zone of Cameroon

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ABSTRACT

The Sudano-Sahelian part of Cameroon is known for its severe climatic conditions and low soil fertility. Local farmers use chemical fertilisers to increase crop production, usually without moderation. As a result, there is environmental pollution such as soil acidification, production of greenhouse gases, and increased eutrophication. To face this situation, scientific research recommends ecological solutions such as bio-fertilisers to enhance soil fertility. In this context, the mycorrhiza symbiosis technology deserves special attention. Indeed, it is a beneficial association between soil fungi (Glomeromycota) and the roots of more than 85% of plants; the evaluation of the agronomic potential of these microorganisms has shown spectacular results under field conditions. This study analyses the status of indigenous arbuscular mycorrhizal fungi in the cowpea rhizosphere in the agro-ecological zone 1 of Cameroon. For this purpose, soil samples were collected from the Far North and North regions of Cameroon. Composite soil samples were obtained by mixing soils collected from three divisions per region. Cowpea was grown in pots on these composite soil samples for 3 months. At maturity, spores of mycorrhizal fungi were isolated and parameters including mycorrhization frequency and intensity, the specific spore's density and richness were evaluated. The spores were characterised according to morpho-anatomical criteria. The results established that between localities, mycorrhization frequency varied between 7-19%; mycorrhization intensity, 7-17.28%; specific density, 0.66-44% and specific richness, 2-4%. Eight specimens of arbuscular mycorrhizal fungi in six genera were characterised: *Acaulospora* (*A. kentinensis*, *A. myriocarpa*); *Ambispora* sp; *Diversispora epigae*, *Funneliformis mossea*, *Glomus* (*G. constrictum*, *G. manihotis*, *and G. maculosum*) and *Rhizophagus intraradices*. *G. constritum* was predominant in all the studied sites, followed by *R. intraradices*, while *Acaulospora myriocarpa* was the rarest. These results pave the way for the selection of indigenous arbuscular mycorrhiza fungi for ecological cowpea production in this area.

Keywords: Status, endomycorrhiza, cowpea, Sudano-Sahelian.

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INTRODUCTION

Soil hosts a wide variety of microbial communities that interact with plant roots in the rhizosphere. These interactions can be very beneficial for plants, as is the case of the symbiotic plant-fungus endomycorrhizal association (Alabouvette and Cordier, 2018, Diedhiou et al., 2022). Indeed, the fungal strains involved in this symbiosis are capable of improving the plant partner's hydro-mineral nutrition (Lambers et al., 2008), drought resistance (Leyval, 2005), yield (Ngakou et al., 2007; Ngakou et al., 2020), resistance to pathogens and pests (Elsen, 2003), and nutrition in polluted environments (Chen et al., 2007, Koffi et al., 2021). In addition, these micro-organisms stabilise soil aggregates by releasing a protein substance called glomalin (Rillig and Steinberg, 2002). Therefore, the technology of this symbiosis, which is now valued in crop production, deserves to be promoted to reduce the use of inorganic fertilisers and pesticides, in order to promote ecological and sustainable agricultural production, (Ngonkeu et al., 2013; Nadjilom et al., 2019; Koffi et al., 2019). On the other hand, leguminous crops such as cowpea, and groundnut contribute enormously to soil fertilisation through symbiotic fixation of atmospheric nitrogen (Bado, 2002). Cowpea in particular is the most important and widely grown food crop in tropical Africa (Snapp et al., 2018). It provides the body with protein (22-33%), sugars (64%), fibre (5.4%) and a significant amount of fat (1.4%) and trace elements (Ca, Fe, etc.). In Cameroon, it is the Sudano-Sahelian zone that constitutes the main area of the production of this commodity (Djouenkeu et al., 2010). Moreover, most of the studies realised on cowpea-microorganisms symbiotic associations in this part of Cameroon, are limited either to associations with Rhizobia, or to tests of exotic commercial mycorrhizal fungi inocula; but yet, several studies have shown the interest of indigenous strains, showing that they are more efficient, as they are ecologically adapted to local planting conditions (Bano and Ashfaq, 2013; Ruiz-Lazano and Azcon, 2000; Enkhtuya et al., 2000). Since this part of Cameroon is particularly exposed to global warming (scarcity of rainfall, prolonged drought, declining soil fertility and agricultural yields, degradation of soil growth, etc.), highlighting the status of endogenous arbuscular mycorrhizal fungi in the cowpea rhizosphere opens up great prospects for the production of specific endomycorrhizal biofertilizers, locally adapted to the cultivation of this plant; the objective of this research is to determine the diversity of endomycorrhizal spores (morphologically) associated with *V. unguiculata*, their distribution in the study area and the level of symbiosis (between the fungi and the plant studied).

MATERIALS AND METHODS

Study site

This work was carried out in the sudano-sahelian zone of Cameroon (North and Far North regions). It is a savannah and steppe zone, characterised by a hot and dry tropical climate. The soils encountered include loam, sandy-loam and vertisol. The rainy season is reduced to three months while the dry season lasts at least seven months. Annual rainfall varies between 800 and 1000 mm per year. The average temperature is 28°C (24-34°C). The vegetation growth period varies between 14 and 180 days. The most abundant plant species are *Boswellia dalzielli*, *Commephora padonculata* and *Hexalobbus monopetalux*. The geographical coordinates of the sites where the soil samples were collected are presented in Table 1.

Soil sampling

To obtain the strains of arbuscular mycorrhizal fungi indigenous to the study area, soil samples were collected from 18 localities in the Far North and North Regions (nine localities per region). In each region, soil collection was carried out in three different divisions. For the Far North region, the randomly chosen divisions were Mayo-Tsanaga, Diamaré, and Mayo-Danay; for the North region, Mayo-Louti, Benue and Mayo Rey were chosen ones. In each division, three localities were randomly selected (but taking into account their accessibility). For each

locality, soil samples were taken from three different fields, at least 5 km apart. Per sampling site, 4-5 kg of soil was collected (between 5 and 15 cm depth). The soils collected per division were mixed together to form one composite sample. A total of 6 composite samples were therefore formed, 3 per region.

Physico-chemical properties of the studied soils

The Palintest 5000 photometer kit was used to assess the physico-chemical properties of the soil samples. The granulometrics parameters that were assessed included sand, silt, clay content. For chemical parameters, pH, conductivity, organic carbon (OC), organic matter (OM), phosphorus (P), magnesium ($Mg2^{+}$) and calcium (Ca^{+}) were analysed. These analyses were carried out at the soil-water-plant analysis laboratory of the Chadian Institute of Agronomic Research for Development.

Trapping of arbuscular mycorrhizal fungi spores

The method of Brundrette et al. (1996) was used for the trapping of arbuscular mycorrhizal spores. *V. unguiculata* was grown in pots using the collected soil samples as substrate (2 kg per pot). These pots were placed on a stand to avoid soil contamination. The plants were watered during rainy weather for three months. At maturity, the plant roots and the substrate (soil) were harvested and transported to the laboratory for analysis.

Microscopic examination of arbuscular fungi in cowpea roots

The finest roots were cut into 1-2 cm lengths, successfully washed, inserted into a test tube containing 10% potassium hydroxide, and heated in a water bath at 90ºC for 30 minutes to thin out the roots. The potassium hydroxide was then removed, the solution was filtered through a sieve before being neutralised by rinsing with acidified water. The neutralised roots were mixed with cotton blue under a water bath for 15 minutes, filtered through a sieve again and rinsed with distilled water. Some roots were mounted in water for direct observations, while others were mounted in glycerine for further observations, Philippe et Hayman, (1970).

Evaluation of cowpea plant's mycorrhization

Mycorrhization frequency

The mycorrhization frequency permitted to estimate the percentage of the studied plant roots infested with arbuscular mycorrhizal fungi. It was calculated according to the method of Arias et al. (2012). 100 root fragments were selected and examined under the microscope. The mycorrhization frequency was the number of root fragments that were found to be mycorrhized among the total number of fragments observed. F (%) = 100 (N-N0)/ N. N is the number of observed fragments and N0 is the number of non-mycorrhised fragments.

The mycorrhization intensity

Mycorrhization intensity is the invasion level of the root cortex by arbuscular mycorrhizal fungi. It was evaluated by assigning to each root fragment a score class between 0 and 5 according to the estimated colonisation of the root cortex by arbuscular mycorrhizal fungi: 0 = no infection, 1 = trace of infection, 2 = less than 10%, 3 = 10 to 50%, 4 = 51 to 90%, 5 = more than 90%.

I (%): ((95n5 + 70n4 + 30n3 + 5n2 + n1)) / N where n5, n4, n3, n2 and n1 are the numbers of the roots noted from 1 to 5 (Sghir et al., 2013).

Isolation and characterisation of arbuscular fungi's spores

Spores were isolated using the wet extraction method described by Gerdemenn and Nicolson (1963): Mix a 500 g soil sample in 4 litres of distilled water; homogenise by mechanical agitation for 15 min (repeat this exercise 3 times); pass this solution through a series of sieves whose size corresponds to that of the spores of arbuscular mycorrhiza fungi (25-50-100-200-300-400 microns); after rinsing the sieves, recover and mix the residue from each sieve in a 60% sucrose solution, then create a density gradient by centrifugation at 3000 rpm; filter the supernatant through a 25

micron sieve and collect the spores in Petri dishes.

Spore size determination

The size of the spores was determined according to the method described by Tobolbaï (2018). The spores were mounted on a slide without being crushed; a graduated ruler is placed 25 cm from the slide and the magnifying lens; with one eye, the spore is observed through the eyepiece of the magnifying glass, while the other eye is focused on the ruler; carefully superimpose the image of the spore on the graduated ruler to obtain the image size in centimetres, the apparent size (Ta); determine the magnification of the magnifying glass (GO): GO = Objective x Eyepiece. In our case, objective = 5.0 and ocular 10, GO = 50. The actual size of the object is: Tr = Ta/GO; the size of the spore is obtained in centimetres and the conversion table was used to evaluate the size in micrometres.

Morpho-anatomical characterisation of isolated spores

After determining the shapes, colours and sizes of the spores, they were mounted between slide and cover slide in a compound: Polyvinyl alcohol-lactic acid-glycerol and Melzer's reagent (V: V, 1: 1) (Beena and Sridhar, 1999). The method of Morton and Beny (1990) was used to determine genera on the basis of morphological criteria. Species identification was carried out by comparing the characterised genera with the original species descriptions and with data from the International Vesicular Mycorrhizal Fungi Collection (INVAM) website (http: //invam.caf.wv.edu/taxonomy/speciesID. htm).

Sporulation evaluation

Specific density

The specific density is the estimation of spore's number in 100 g of soil sample. It was calculated according to the method of Arias et al. (2012). D (%): N/100 where N is the number of spores counted and 100 is the amount of soil used for their isolation.

Specific richness

Specific richness is the number of different genera or specimens of arbuscular fungi spores found in a collection of isolated spores. It was assessed according to the method of Arias et al. (2012). R (%): 100 (Number of different genera of arbuscular fungi)/(Total number of spores counted).

Shanonne diversity index

This value is used to assess the level of diversity within the identified arbuscular fungi community. H '= - Σpi.log2.pi where pi is the portion of species i in the total number of species (S) in the studied environment. P(i) is calculated as follows: p(i) = (ni)/N where ni is the number of individuals for species i and N is the total population (Shanonne and Weaver, 1948).

Statistical analysis

The data were statistically analysed using "statgraphics 5.0" program which performs analysis of variance (ANOVA). The means of the results for the different localities were separated using the least significant difference (LSD) at the indicated probability level. Pearson's correlation was used to analyse the correlations between the different studied parameters. The relationships between the different parameters were determined by the Pearson correlation coefficient.

Table 1: Geographic coordinates of sites where soil samples were collected.

Regions	Divisions	Localities	Altituds (m)	Latituds°	Longituds°
	Mayo-Tsanaga	Mokong	326	10.58731	14.00415
		Mokolo	317	10.7412	13.7986
		Koza	371	10.86547	13.89596

Far North	**Diamaré**	Maroua	408	10.61877	14.35906
		Gazawa	482	10.53025	14.13976
		Dargala	357	10.53077	14.93538
	Mayo-Danay	Kalfou	357	10.28578	14.93538
		Yagoua	357	10.32601	15.24176
		Vele	331	10.49614	15.18793
North	**Mayo-Louti**	Mayo-Oulo	494	9.95649	13.62433
		Guider	384	9.92437	13.93035
		Figuil	298	8.76711	13.35941
	Bénoué	Bibemi	247	9.30813	13.8870
		Ngong	327	9.02162	13.49671
		Garoua	295	9.31311	13.36625
	Mayo Rey	Mayo-Galké	311	8.38526	14.17865
		Tcholiré	401	8.41254	14.17865
		Marandi	297	8.52431	14.10856

RESULTS

Soils physico-chemical properties

Table 2 shows that the pH varies from 4.32 to 5.30 between the different soil samples from the two regions. Acidity is higher in Mayo Danay (4.97) (Far North) and lower in Mayo-Louti (5.30), (Northern region) ($P<0.001$). For the main fertiliser minerals, phosphorus content is significantly higher in Mayo-Louti (86ppm) and lower in Benue (30 ppm), while potassium content is lower in Mayo Danay (365 ppm) and higher in Mayo-Rey and Benue (450 ppm) ($P<0.001$). For particle size parameters, soils in Mayo-Tsanaga were found to be the sandiest (73.20%), and therefore less silty (14.84%); they also have the lowest conductivity (150) ($P<0.001$). The rate of return of organic matter to the soil was significantly lower in Diamaré (0.0105%) and higher in Mayo-Tsanaga (0.116) ($P<0.001$).

Evaluation of the endomycorrhizal symbiosis

Mycelial hyphae and spores are the mycorrhizal structures that were most observed on thinned and stained roots (Figure 1). Hyphae are used by the fungi to take up mineral elements from the soil and water; spores are the organs of propagation. Spores were the most observed elements. However, the presence of arbuscules has not been demonstrated, probably because this element of mycorrhizal fungi is not permanent and eventually degenerates.

Estimation of mycorrhization

Mycorrhization frequency

The percentage of roots infested by mycorrhizal fungi is significantly higher in Mayo-Tsanaga (19.33%) and lower in Mayo-Rey (7%), compared to the other regions ($P<0.0001$). The comparison of values between the two regions (Far North and North) shows no effect: The values recorded in some areas of the Northern region are lower than those noted in some areas of the Far North and vice versa.

Mycorrhization intensity

The degree of root cortex colonisation, or mycorrhization intensity (Figure 3), was significantly higher in Mayo-Tsanaga soils (17.28%, $P = 0.0001$), and conversely lower in Mayo-Louti (7.8%), Mayo-Rey (7%) and Diamaré (8%). No trend was observed per region.

Estimation of arbuscular mycorrhizal fungi sporulation

Specific density

The evaluation of spore density (Figure 4) shows that soils in the Mayo-Tsanaga division are significantly richer in spores (4.4%) compared to those in the Mayo Danay division which are the poorest (0.66%) (P = 0.0004). On the other hand, no significant difference was observed between the sporulation values recorded in the northern zones (Mayo-Louti 3.75%, Benue 3.95% and Mayo-Rey 3.98%). It should be noted that sporulation is uniform in the Northern region and variable between the zones of the Far North region.

Specific richness

Figure 5 shows the morphotypic diversity or species richness of the soil samples analysed. It can be seen that soils from Mayo-Rey division have a lower diversity of arbuscular fungal spore morphotypes (2%), while soils from Mayo-Tsanaga division have the highest percentage (4%) (P<0.02). There was no significant difference between the species richness of the Mayo-Louti (3%), Benue (2.8%) and Diamaré (2.8%) divisions. It appears that the regions did not influence the morphotypic diversity of spores in the soils.

Correlation between mycorrhization parameters and soil physico-chemical characteristics

Analysis of the relationship between mycorrhization parameters and the physical and chemical characteristics (Table 2) of the soils reveals that mycorrhization intensity and frequency are positively related and highly significant (r = 0.99, p = 0.0001), mycorrhization intensity increases with the frequency of mycorrhization; species richness is positively related to the frequency and intensity of mycorrhization (r = 0.79, p = 0.05). This establishes that when a soil has a high mycorrhizal potential, the percentage and degree of colonisation are high. Specific density was positively related to sand content (r = 0.87, p = 0.02) and clay (r = 0.93, p = 0.005), indicating that an ideal soil for the development of arbuscular mycorrhizal fungi requires a certain clay-sand ratio. Furthermore, no significant correlation was found between soil nutrients (P, K, Mg, M.O, and C.O), pH and mycorrhization parameters (mycorrhization frequency, mycorrhization intensity, density and species richness). This may indicate that the arbuscular fungi in the study area are tolerant of high levels of these minerals in the soil and of acidity.

Morpho-anatomical characterisation of isolated spores

Morphological characterisation of the isolated spores showed the presence of 8 specimens of different arbuscular mycorrhizal fungi: *Glomus constrictum* (Figure 6), *Acaulospora kentinensis* (Figure 7), *Glomus maculosum* (Figure 8), *Glomus manihotis* (Figure 9), *Rhizophagus intraradices* (Figure 10), *Diversispora epigae* (Figure 11), *Funneliformis mossea* (Figure 12), *Ambispora* (Figure 13).

Spores distribution in the study area

Analysis of the spatial distribution of the characterised spores shows that they are not uniformly distributed in the study area. *Glomus constrictum* is the most representative specimen (abundance fluctuating between 131-1117) and the most widespread (present in the six divisions studied). This fungal specimen shows a better adaptation (ubiquity) to the edaphic and environmental diversity of the Sudano-Sahelian zone of Cameroon. It is followed by *Rhizophagus intraradices* (abundance varying among 2 -137) and present in the six divisions of both regions. *Acaulospora myriocarpa* is the rarest specimen (abundance around 1) and has only been found in Mayo-Danay (endemic to this zone).

On the other hand, Shanonne's diversity index (H ‘) is higher for soils in Mayo-Tsanaga (H ' = 0.89), indicating that its specific diversity is higher than for other zones and lower than for Mayo-Rey.

Table 2: Soils physico-chemical characteristics.

	pH	Sand	Silt	Clay	Cond	O.C (%)	O.M	P (ppm)	K (ppm)	Mg2+
Mayo-Tsanaga	5,13cd	73,20e	14,84a	11,91a	150,4a	0,067bc	0,11c	43b	405b	60a
Diamaré	5,02 b	12,86a	42,62d	44,55e	166,4b	0,061a	0,01a	72d	560e	410f
Mayo-Danay	4,97a	27,78b	25,69c	46,32f	268f	0,066bc	0,11bc	43b	365a	115c
Mayo-Rey	5,02 b	71,52d	15,68b	12,79b	232d	0,065ab	0,11ab	56c	450d	95b
Bénoué	4,98 a	71,10d	14,00a	14,89c	250e	0,065ab	0,11bc	30a	450d	180e
Mayo-Louti	5,30d	57,45c	15,60b	26,93d	175,2c	0,066bc	0,11bc	86e	430c	135d
P-value	**<0,001**	**<0,001**	**<0,001**	**<0,001**	**<0,001**	**<0,001**	**<0,001**	**<0,001**	**<0,001**	**<0,001**

O.C: Organic carbon; O.M: Organic matter; cond: Conductivity.

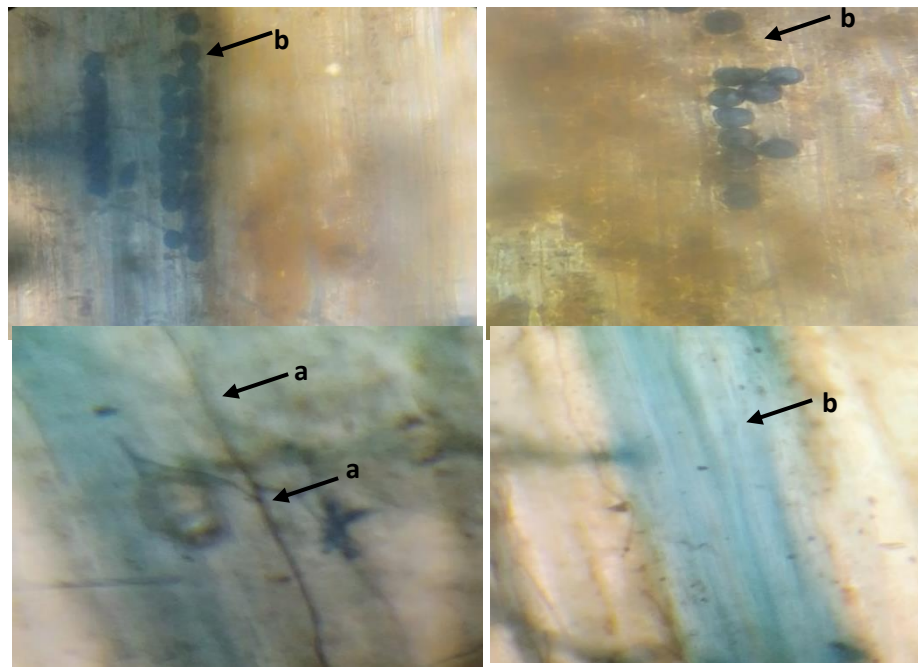

Figure 1: Fragments of the thinned and coloured cowpea roots.
a: Mycelial hyphae ; b : Spores of arbuscular fungi.

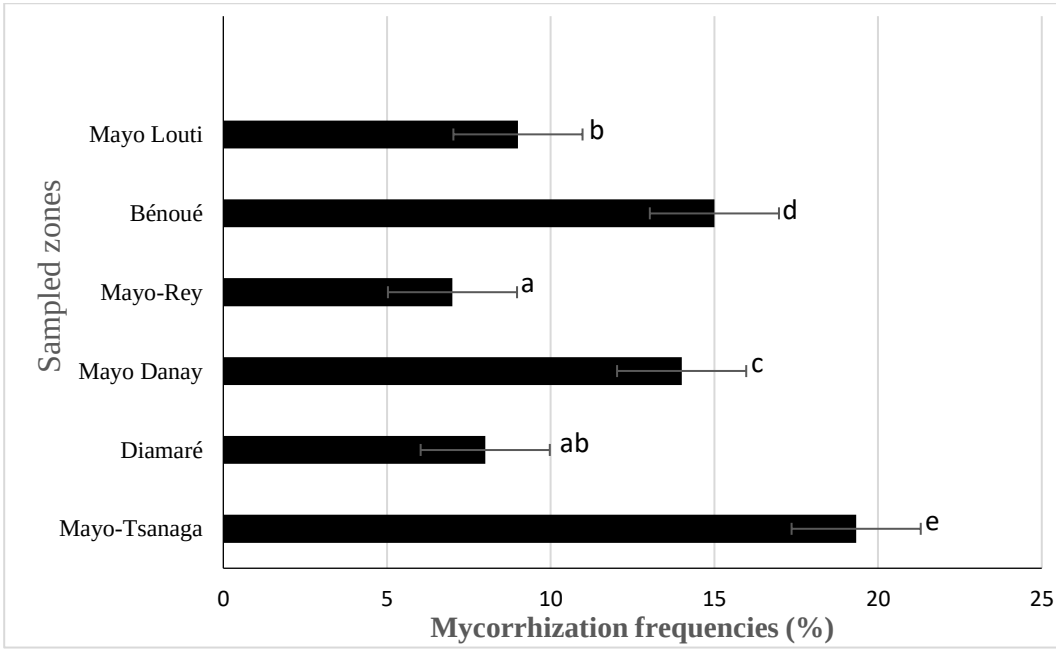

Figure 2: Frequency of mycorrhization.
P<0.0001, F = 617.87
Values attributed with the same letters (a, b, c, d, e) aren't significantly different at 5% threshold.

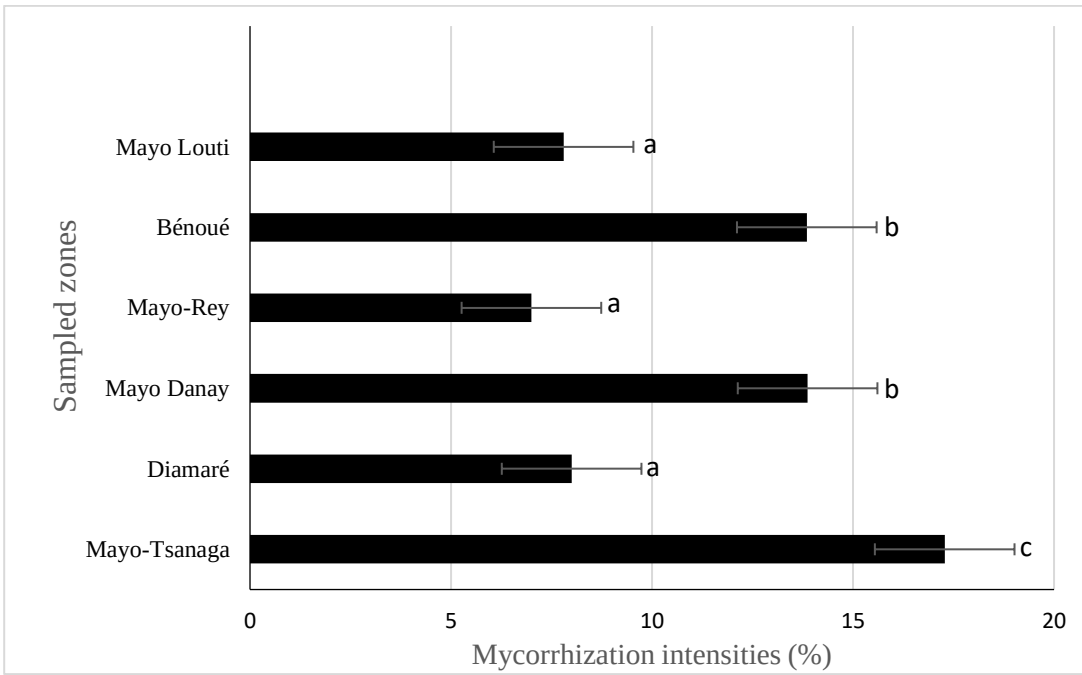

Figure 3: Intensity of mycorrhization.
P = 0.0001, F = 284.99
Values attributed with the same letters (a, b, c) aren't significantly different at 5% threshold.

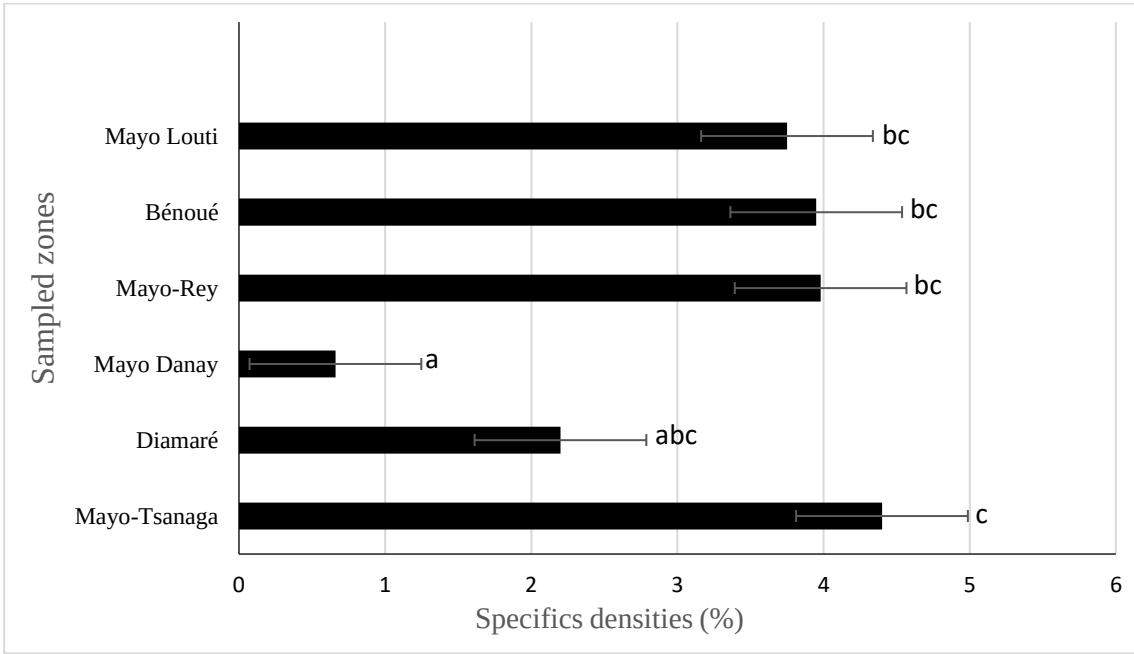

Figure 4: Specific density.

P = 0.0004, F = 1.74

Values attributed with the same letters (a, abc, b, bc) aren't significantly different at 5% threshold.

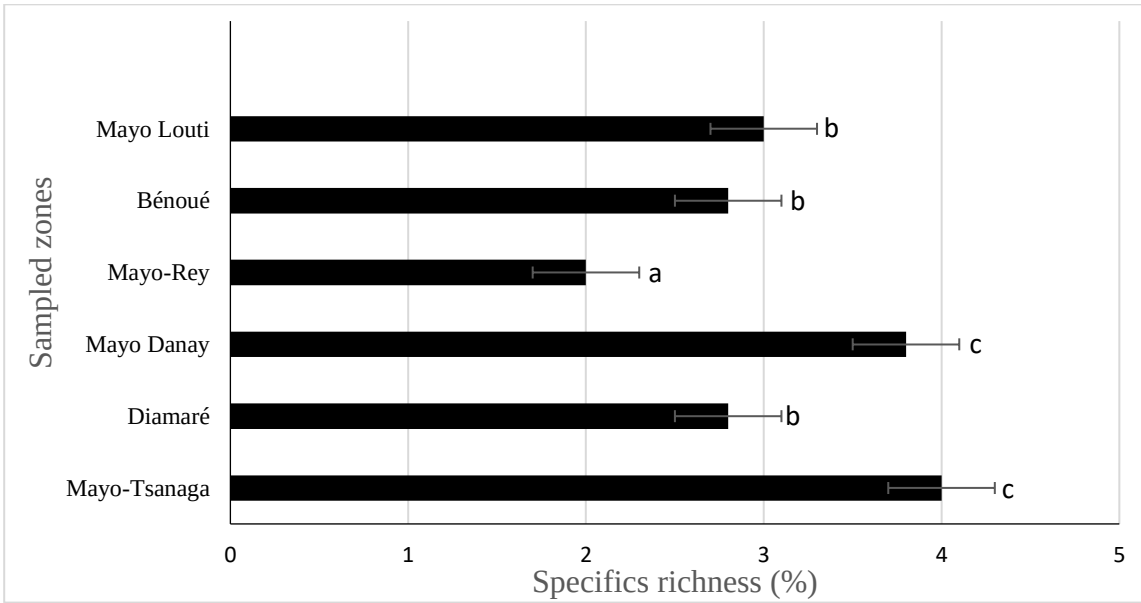

Figure 5: Specific richness.

P <0.02, F = 3.15

Values attributed with the same letters (a, b, c) aren't significantly different at 5% threshold.

Glomus constrictum (Trappe, 1977).

Table 3: Correlation between the mycorrhization parameters and the physico-chemical properties of soils.

	F (%)	**I (%)**	**D (%)**	**R (%)**
F (%)		0,99	0,15	0,79
		(6)	(6)	(6)
		0,0001	0,76	0,058
I (%)	0,99		0,051	0,79
	(6)		(6)	(6)
	0,0001* **		0,92	0,056
D (%)	0,159	0,051		-0,266
	(6)	(6)		(6)
	0,76	0,092		0,60
R (%)	0,79	0,79	-0,266	
	(6)	(6)	(6)	
	0,058*	**0,056***	0,60	
P	-0,70	-0,75	0,043	-0,27
	(6)	(6)	(6)	(6)
	0,11	0,08	0,93	0,59
pH	0,40	0,32	0,57	0,36
	(6)	(6)	(6)	(6)
	0,427	0,53	0,23	0,47
K	0,55	0,55	0,02	0,55
	(6)	(6)	(6)	(6)
	0,25	0,24	0,98	0,25
Magnésium	0,44	0,41	0,38	0,27
	(6)	(6)	(6)	(6)
	0,37	0,41	0,45	0,59
C.O	0,58	0,54	0,34	0,34
	(6)	(6)	(6)	(6)
	0,22	0,26	0,50	0,69
M.O	0,43	0,40	0,37	0,20
	(6)	(6)	(6)	()
	0,39	0,43	0,46	0,69
Cond	0,026	0,062	0,39	0,18
	(6)	(6)	(6)	(6)
	0,96	0,90	0,44	0,72
Sand content (%)	0,33	0,25	0,87	0,14
	(6)	(6)	(6)	(6)
	0,52	0,62	**0,02***	0,78
Clay content (%)	-0,27	-0,20	0,93	0,23
	(6)	(6)	(6)	(6)
	0,59	0,70	**0,005****	0,65
Silt content (%)	-0,37	-0,3	0,69	-0,004
	(6)	(6)	(6)	(6)
	0,47	0,56	0,12	0,99

*** = Very highly significant; ** = highly significant; ns = Not significant; F (%) = Frequency of mycorrhization; I (%) = Intensity of mycorrhization; P (mm): Available phosphorus; C.O = Organic carbon.

Table 4: Distribution of arbuscular fungal spores in the study area.

	Mayo Tshanaga	**Diamaré**	**Mayo-Danay**	**Bénoué**	**Mayo-Rey**	Mayo-Louti
G. constrictum	1117	515	131	1075	656	959
G. maculosum	43	1	2	4	0	0
G. manihostis	0	5	1	0	0	0
A. kentinensis	3	0	1	0	0	0
R. intraradices	49	9	10	137	2	72
Ambispora	31	0	2	0	0	0
A. myriocarpa	0	0	1	0	0	0
F. mossea	1	0	2	0	0	2
D. epigae	26	2	0	1	25	25
H'	**0,89**	**0,11**	**0,78**	**0,34**	**0,031**	**0,35**

H'= Shannon diversity index.

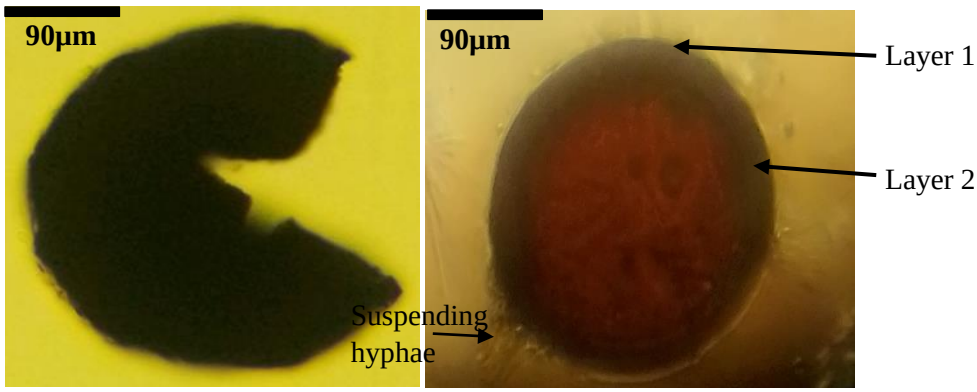

Figure 6: Morpho-anatomical description of *Glomus contrictum.*

1. *Acaulospora kentinensis* (Kaonangbua et al., 2010)

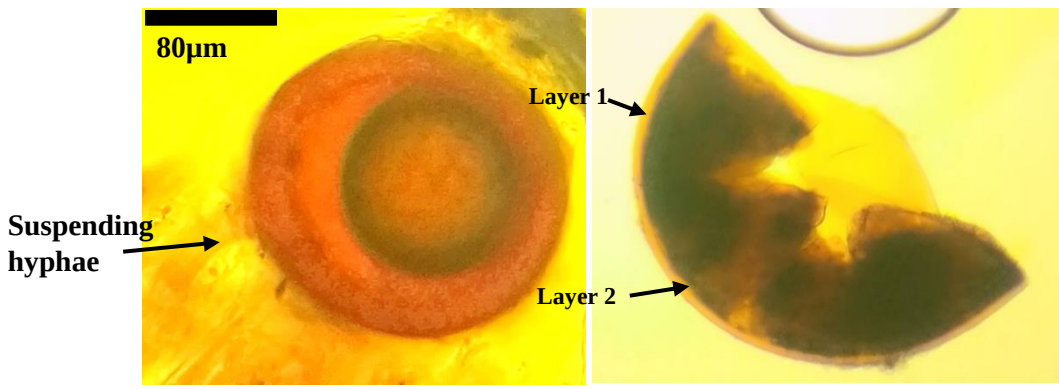

Figure 7: Morpho-anatomical description of *Acaulospora kentinensis.*

2. *Glomus maculosum* (Mill and Walker, 1986)

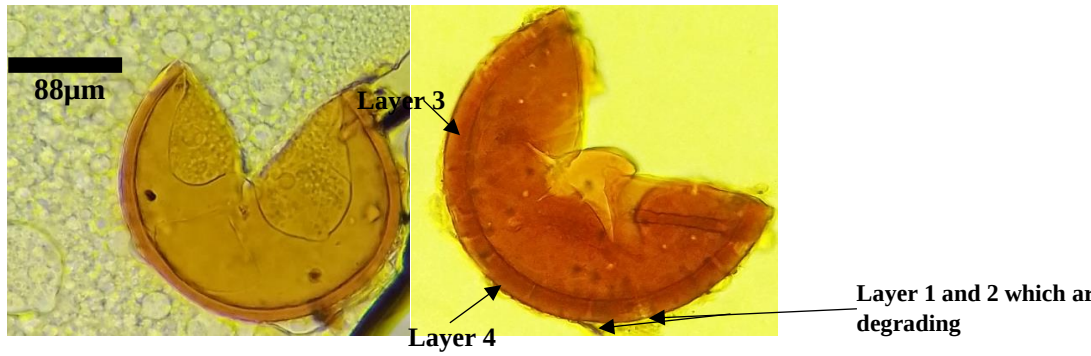

Figure 8: Morpho-anatomical description of *Glomus maculosum*.

3. *Glomus manihotis* (Schenk et al., 1984)

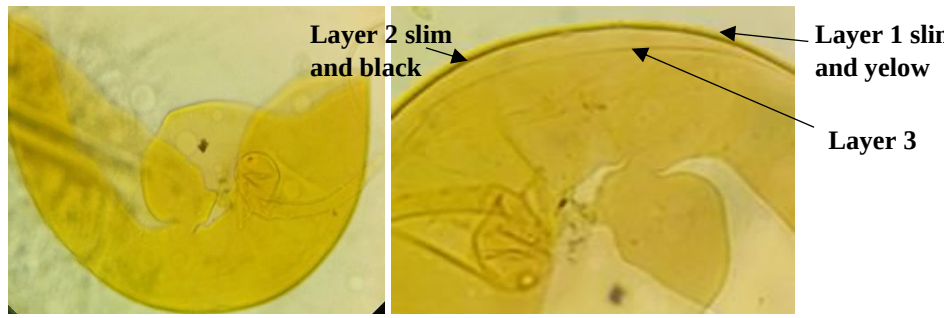

Figure 9: Morpho-anatomical description of *Glomus manihotis.*

4. *Rhizophagus intraradices* (Schenk, 1982)

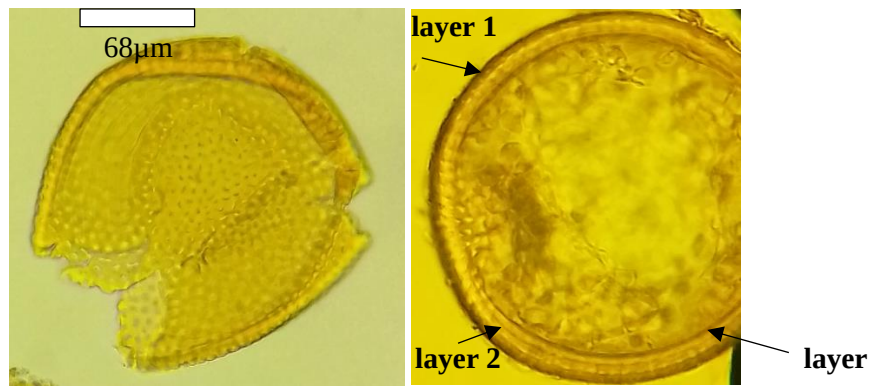

Figure 10: Morpho-anatomical description of *Rhizophagus intraradices.*

5. *Diversispora epigae* (Walker and Schubler, 1979)

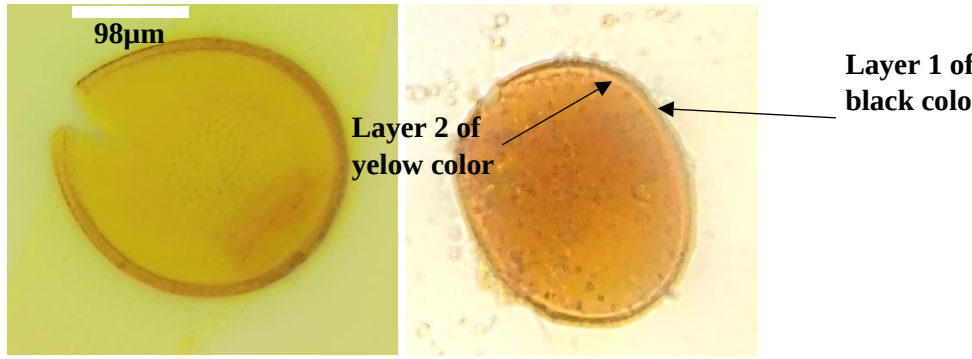

Figure 11: Morpho-anatomical description of *Diversispora epigae.*

6. *Funniliformis mossea* (Mill and Walker, 1986)

Figure 12: Morpho-anatomical description of *Funneliformis mossea*.

7. *Abispora* sp (Walker, 2008)

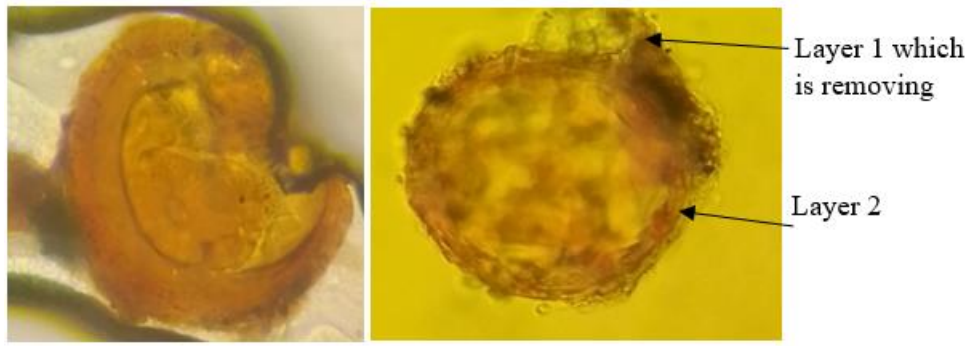

Figure 13: Morpho-anatomical description of *Ambispora.*

DISCUSSION

High soil acidity is a limiting factor for agricultural production, as it is rather the relatively neutral pH that is required for most crops (Doucet, 2006). Soil pH is a synthetic expression of physicochemical conditions that partly govern soil structure, microbial activity and nutrient availability (Genot et al., 2007). When the soil is acidic, some nutrients become unavailable to plants while some toxic elements are more available, Singer and Ewing (2000). The structural parameters of the soil (clays, organic matter) are very dependent on the microbial activity that ensures the transfer

of matter and energy in the soil, (Lavelle and Spain, 2001). The degradation of the physical properties of a soil can considerably modify its qualities and the microflora are very sensitive to changes in their habitats.

The mycorrhizal frequency data are lower than those of Bansal et al. (2012) in India who obtained a 100% colonisation rate in cowpea by studying the diversity of arbuscular fungi in some crops as well as those reported by Al-Areqi et al. (2013) in Yemen who reported that the mycorrhization frequency of *Coffea arabica* varied between 48 and 100%. The difference between these results may result from the physicochemical characteristics of each studied soil. Regarding mycorrhization intensity values, similar results were reported by Tobolbaï et al. (2018) who recorded a mycorrhization intensity of 15% in maize in North Cameroon. However, these values are higher than those of Nadjilom et al. (2019) who obtained a mycorrhization intensity that fluctuates between 0.8-2.9 percent with rice in the Sahelian zone in Chad. The mycorrhizal potential of the different soils studied may justify this difference.

For specific density, Haougui et al. (2013) in Niger, recorded higher data than these; they obtained as specific spore density in vegetable crop sites, 28.48%. Arias et al. (2012) reported similar results in a study on the diversity of arbuscular fungi in the coffee rhizosphere in Mexico, which recorded variations in spore density ranging from 137 to 387 (1.37-3.87%). The species richness results corroborate those of Stutz et al. (2000) who reported variations in species richness between 6-12 in a study on the diversity and distribution of arbuscular fungi spores in Namibia and southwestern North America, as well as of those of Bhattacharjee and Sharma (2011), who obtained a species richness of 1.7% in a study on the diversity of arbuscular fungi associated with three rice cultivars in India.

Regarding the link between soils and mycorrhizal parameters, our observations confirm the results of Ngakou et al. (2020) who showed that a substrate composed of 2/3 soil and compost added to 30g mycorrhizae is ideal for garlic production by mycorrhizal fertilisation. For the distribution of mycorrhizal spores in the study site, Tobolbaï et al. (2018) obtained similar results, reporting that *Glomus constrictum* is the most abundant specimen in the rhizosphere of maize grown in North Cameroon. These observations are also in agreement with those of Nadjilom et al. (2019) who showed that *Glomus constritum is the* most abundant specimen in the rhizosphere of rice in the Sahelian zone in Chad.

Conclusion

This work is an analysis of the status of endogenous endomycorrhizal fungi associated with cowpea in the Sudano-Sahelian zone of Cameroon. Our results show that cowpea mycorrhization is variable between the localities studied. Eight specimens of arbuscular fungi in six genera are present in the rhizosphere of this legume in the agro-ecological zone 1 of Cameroon, with the predominance of *Glomus constrictum*, followed by *Rhizophagus intraradices* while *Acaulospora myriocarpa* is the rarest specimen. Knowledge of these fungi opens the way for selection tests to screen for the most suitable mycorrhizal fungi strains to promote cowpea growth and yield in this part of Cameroon.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

RT: Carrying out field and laboratory experiments, processing data and writing the document. AN: Scientific supervisor of the work. STT: Collaborator in the conduct of fieldwork and laboratory work. SA: Contribution of expertise for the conception of the subject, accompaniment during the conduct of the work (lines of work, analyses to be carried out).

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