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Potential of endogenous arbuscular mycorrhizae fungi to improve soybean (*Glycine max* L.) production in northern regions of Cameroon

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ABSTRACT

Background and objective: Soybean production can be increased through mycorrhizal biofertilizers application. Endogenous mycorrhiza species play a key role in this process. But in northern regions of Cameroon, most of the studies carried out in this domain have focused on exotic commercialized strains. This work aims to evaluate the performance of endogenous mycorrhiza on the promotion of growth and yield of soybean in northern regions of Cameroon. *Methodology and Results***:** Mycorrhizal spores were trapped and isolated from soil samples collected in 9 localities per northern region. The extracted spores was massively multiply in pot to be use as biofertilizer and four treatments were formulated : T1: consortium of spores isolated from the soybean rhizosphere cultivated on soil samples from the Far North region, T2: consortium of spores isolated from the soybean rhizosphere cultivated on soil samples from the North region, T3: consortium of isolated spores from the soybean rhizosphere cultivated on the soils of Adamawa, T4: Mixture consortium of isolated spores from the soybean rhizosphere cultivated on the soils of this three regions. Tests in field conditions have been implemented in three different localities: Dang in Adamawa region, Touboro in the North region and Bitcharé in the Far North. The access parameters were: size, biomass, pods number, pod weight, seed number, seed weight, and yield per hectare. The results analysis after 90 days of growth revealed that all treatments boosted soybean growth and yield under field conditions. For all the tests carried out in the three localities, the best improvements in growth and yield were obtained with the T1 treatment: Size (+47.32 cm), biomass (+ 241.05g), pods number (+285.71), pods weight (+154.2g), seeds number (+500), seeds weight (+ 314.28g) and yield per hectare (+ 870kg). The results obtained with the T2 and T4 treatments were weaker (size: +5.5 cm, biomass: + 1.5g, pods number: +5, pods weight: + 2.5g, seeds number: +50, seed weight: + 10.6g, yield per hectare: + 38kg). The localities (environmental factors) significantly influenced the effect of treatments on the growth and yield parameters of the legume under investigation. However, the four treatments showed a similar global adaptability in the study area. T1 and T3 showed the best performances for a sustainable production of soybeans in the northern regions of Cameroon. Our results indicate that the endogenous arbuscular mycorrhiza from soybean rhizosphere, especially the mixture of native spores of the three northern regions

(T4) or those isolated on Adamawa region (T1) soils can effectively boost growth and yield of soybean plant. Thus, this technology can be popularized in Cameroon to market bio-fertilizers, less expensive, efficient and ecological.
Key words: Soybean, arbuscular mycorrhizae, endogenous, northern, growth, biomass, pod, seeds, yield.

INTRODUCTION

While the beneficial effects of chemical fertilizers on crop productivity are satisfactory, their miss use can seriously affect the environment: Soil degradation, increase of eutrophic zones and water pollution are some of the damages the can cause, (FAO, 2019). Today, the approach of sustainable development has orientated attention on the ecological methods through the use of benefical microorganisms, (Vogo *et al*., 2013; Tobolbaï *et al*., 2018, FAO, 2016). In this way, several studies have shown that some symbiotic soil microorganisms (mycorrhizae, rhizobia) are capable to improve plants growth and crops yield (Ngakou *et al*., 2007, Ogou *et al*., 2018, Khosro *et al*., 2012, A.T. *et al*., 2020). Among these symbiotic soil microorganisms, arbuscular mycorrhiza are the most widespread (Barea *et al.*, 1993). In addition of mycorrhizae advantages on growth and plant yield, the present several others benefits, particularly, the survival of plants, their biodiversity, their impact on soil microflora and the potential for reducing both abiotic and biotic stresses (Dalpé, 2005). Despite of their importance, arbuscular mycorrhizae are not exploited and almost ignored by Cameroonian farmers (Ngonkeu *et al*., 2013). Most of the work on mycorrhizae in the northern regions of Cameroon are focused on exotic strains and formulations; little information is available on the efficiency and agronomic performance of native strains. On the other hand, the FAO, (2009) report estimates that protein consumption in Cameroon is 16g/person/day; this value is far below the recommended minimum threshold of 30g/person/day. The crops of food legumes, recognized for their richness in proteins, energies and trace elements deserve to be encouraged to face this situation. Due to its importance in dietary habits, soybean is one of the main legumes cultivated in Cameroon (CIRAD, 2013). The present study evaluates the field impact of endogenous strains of arbuscular mycorrhiza fungi on the growth and yield of soybeans in the northern regions of Cameroon.

MATERIAL AND METHODS

Experimental study site: The work was carried out in agro-ecological zones 1 (Far North and North regions) and 2 (Adamawa region) of Cameroon, from July to October 2018. The experiments were done in three localities: Dang in the Adamawa region, Vina Division, Ngaoundéré 3^{trd} Sub-Division; Touboro in the North region, Mayo-Rey Division, Touboro Sub-Division, Bitcharé in the Far North region, Mayo-Kani Division, Moulvoudaye Sub-Division. The temperature during the experimentation period varies between 21° and 35° C in Bitcharé and Touboro, and 16° to 27° C in Dang; The rain fluctuates between 195-25 mm in Touboro and Bitcharé and between 270-130 mm in Dang (Atlas du Cameroun, 2018). Table 1 summarizes the geographic coordinates of the study sites.

Table 1: Geographical coordinates of the study sites

Regions	Localities	Altitudes (m)	Latitudes°	Longitudes°
Adamawa	DANG	1090	07.41049°	13.54827
Far North	BITCHARE	358	10.28578	14.93537
North	TOUBORO	312	8.38527	14.1789

Plant material: The soybean seeds used were those of traditional varieties used by local farmers. At least 3 varieties of soybeans are cultivated in the northern regions of Cameroon (FAO, 2009).

Figure 1: Seeds of soybean used

Soil collection and spore extraction: Soil samples were taken in 9 localities per northern region. Spores of mycorrhiza were trapped in pots using soybean as host plant. At maturity, these spores were isolated according to the method of Gerdemenn et Nocholson, (1963) and characterized. Richard *et al*. (2021) showed that the diversity of CMA spores associated with soybeans in the Far North region consists of: *Glomus constrictum, Glomus maculosum, Glomus manihotis, Acaulospora kentinensis, Rhizophagus intraradices, Ambispora sp, Acaulospora myriocarpa* and *Diversispora epigae*. In the northern region, this diversity includes: *Glomus constrictum, Glomus maculosum, Acaulospora kentinensis, Rhizophagus intraradices, and Diversispora epigae*. For the Adamawa region, Tobolbai R, (2018) found that this diversity includes: *Glomus constrictum, Rhizophagus intraradices, Glomus maculosum, Diversispora epigae, Funneliformis mossea and Glomus manihotis*.

Production of mycorrhizal inoculum: The isolated spores were massively multiplied in pot (2 litres) conditions using the study plant as host plant. The growing medium is a mixture of sand and soil (taken from more than 3 m deep) (v: v / 2: 1) and this mixture has been sterilized. The pots were placed in such a way as to avoid any contamination from the ground or the wind. The plants were subjected to direct rainwater so that the conditions of inoculum production remain close to natural conditions, since it is intended for direct use in the field. At maturity, the above-ground biomass is eliminated and the soil substrate as well as the roots were harvested to constitute a raw inoculum composed of spores of arbuscular fungi and mycorrhiza roots.

Treatments formulation: Four different treatments were constituted from the consortium of isolated and multiplied spores. The performance of a mycorrhizal biofertilizer is related to the complementarity or antagonism between specimens of arbuscular fungi and their adaptation to the environment. Thus, the mycorrhizal species composition of the different formulations was maintained as encountered under natural conditions. The different treatments formulated were as follows: T0: negative control (having received no treatment); T1: consortium of spores isolated from the soybean rhizosphere cultivated on soil samples from the Far North region, T2: consortium of spores isolated from the soybean rhizosphere cultivated on soil samples from the North region, T3: consortium of isolated spores from the soybean rhizosphere cultivated on the soils of Adamaoua, T4: Mixture of consortium of isolated spores from the soybean rhizosphere cultivated on the soils of the Far North, North and Adamawa region.

Experimental set-up: In each experimental site, the experimental design is a completely randomized block, with 4 treatments and a negative control, each being repeated 3 times. An experimental plot covers an area of 18 m^2 on which we have 1200 soybean plants separated from each other on the line of 20 cm and 30 cm between the lines (density = 90 plants / m^2). Figure 3 illustrates the experimental design in each locality.

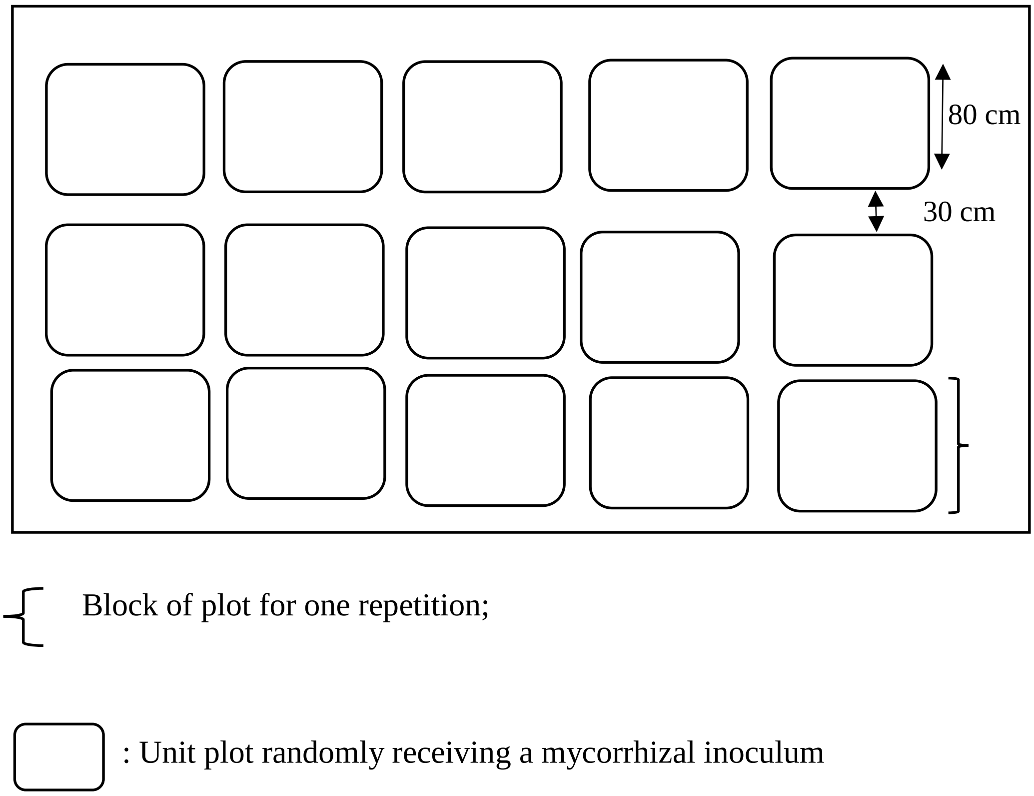


Figure 3: Experimental set-up in the field in each locality

Field application of endomycorrhizal inoculum: The mycorrhizal inoculum application to crops have been carried out in two phases: the coating of the seeds with the mycorrhizal inoculum at sowing period and the infestation of plants roots with the mycorrhizal inoculum after 4 weeks of growing: averagely 100g of the inoculum have been introduced into plant rhizosphere. This dual application is intended to increase chances of successful inoculation. In fact, when the inoculum is coated with the seeds or deposited in the pockets, the roots of the plant may miss them. A heavy rain or a flood for example are capable to change the position of the spore in the soil or even totally leaching it out.

Assessment of growth and yield parameters: Growth parameters were evaluated 90 days after sowing. The plants were harvested and dried in the shade for three months. Each parameter was evaluated using 20 plants per treatment: Size, total biomass, pods number, pods weight, seeds number, seed weight and seed yield per hectare. Weights were measured using a precision electronic balance. The yield per hectare was evaluated according to the following formula (Tobolbaï R, 2018):

$$\mathbf{YH} = \frac{\mathbf{WNS}}{\mathbf{1000}}\mathbf{x90000}$$

Where 90000 is the theoretical number of plants per hectare, **WNS** is the weight of the average seeds number per plant in grams.

Estimation of gain over control for each treatment : The benefit compared to the control for each treatment was calculated using the following formula:

$$\mathbf{BM} = \frac{(\mathbf{TM} - \mathbf{T})}{\mathbf{T}}\mathbf{X\ 100}$$

BM: Gain compared to the control in %, TM: Value of a given parameter receiving one treatment, T: Value of the parameter of the control plants.

The overall performance of each treatment in the two agro-ecological zones was estimated by calculating the arithmetic mean of the mycorrhizal response recorded in the three localities.

Statistical analyses: The data were statistically analysed using the "statgrahic 5.0" program which performs analysis of variance (ANOVA). The means of results from different localities were separated using the least significant difference (LSD) at the threshold of the indicated probabilities.

RESULTS

Isolated mycorrhiza spores

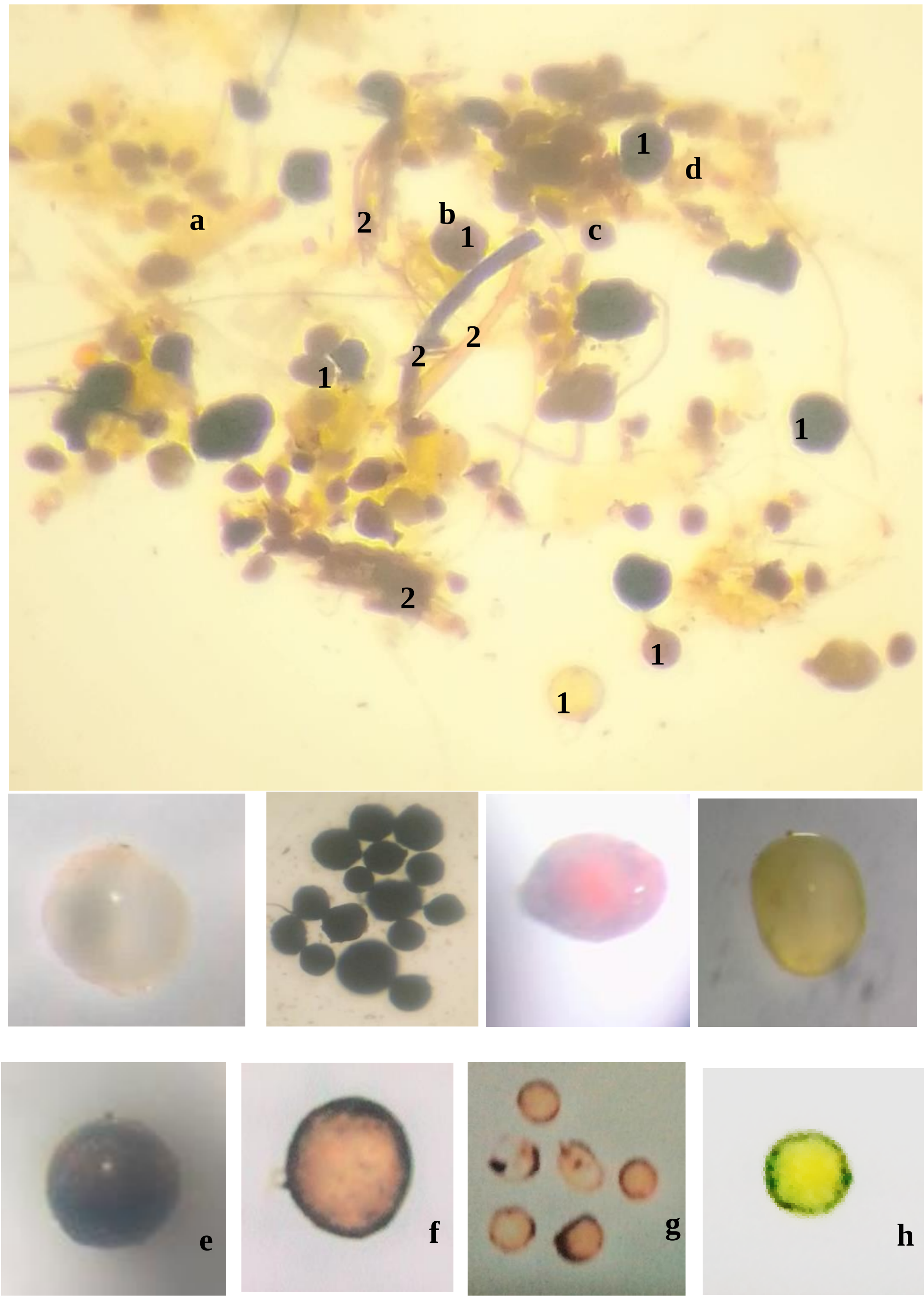


Figure 4. Aspects of extracted spores
1: Spores, 2: debris; a, b, c, d, e, f, g, h: different spores' phenotypes

Effects of the four treatments on soybeans growth 90 days after sowing: Table 2 shows that all the four treatments have significantly (P≤0.05) induced an increase in soybean size and biomass in each locality. For the size, the improvements are more higher with T1 (55.1 ± 4.58 cm), and weaker with T2 (46.36 ± 4.41cm) and T4 (46.4 ± 4.75cm) at Dang (Adamawa region); in Touboro (North region), the increases are similar between T1(37 ± 2.9) and T3 (35.53 ± 3.13) which are higher, and lower with T4 (34.32 ± 1.68); In Bitcharé (Far North region), T2 (29.55 ± 2.26) shows the lower performance, while results with T1 (34.2 ± 2.35), are the highest. Regarding biomass, in Dang the plots having received the T1 treatment (16 ± 2.13) show higher values, unlike those having received the T4 treatment (8.64 ± 2.2) which have lower values, (P = 0.0008). In Touboro, the effects of T1 treatments (10.3 ± 3.87) are better, while those of T2 (8.9 ± 1) and T3 (9.6 ± 0.66) are not significantly different, and higher than the effects of T4 treatment (7.65 ± 0.86). In Bitcharé, it is always the biomass with T2 (3.91 ± 0.5) which is lower, while the values noted at T1 (6.10 ± 1, 3), T3 (5.63 ± 1.6) and T4 (6.52 ± 1.2) are the same and higher, P≤0.05.

Table 2: Effects of treatments on soybean growth

	Sizes			Biomass		
Treatments	**Dang**	**Touboro**	**Bitcharé**	**Dang**	**Touboro**	**Bitcharé**
T0	37,4±2,5a	29,3±3,35a	26,45±2,13a	5,04±1,76a	3,02±0,8a	2,45±0,7a
T1	55,1±4,58d	37±2,9c	34,2±2,35d	16±2,13d	10,3±3,87d	6,52±1,2c
T2	46,36±4,41b	34,85±1,81b	29,55±2,26b	13,58±3,2c	8,9±1c	3,91±0,5b
T3	52,17±3,4c	35,53±3,13bc	32,05±2,85c	14,98±2,11cd	9,6±0,66c	6,10±1,3c
T4	46,4±4,75b	34,32±1,68b	32±3,05c	8,64±2,2b	7,65±0,86b	5,63±1,6c
P-values	**0,0037**	**0,0491**	**0,0500**	**0,0008**	**0,0057**	**0,0067**
F-values	**7,98**	**3,5**	**3,11**	**11,94**	**7,09**	**6,75**

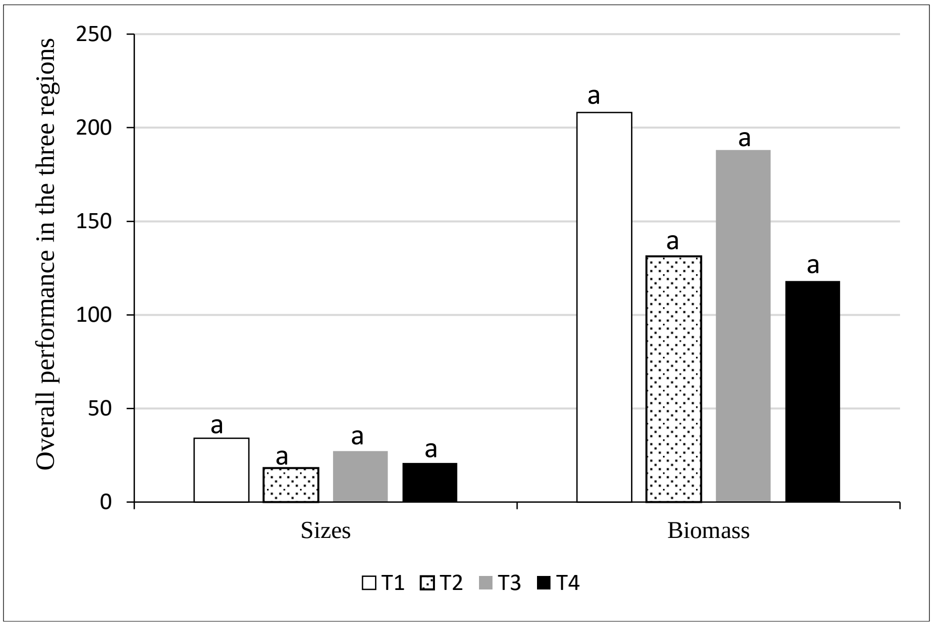
Values followed by the same letter are not significantly different at the 5% probability level.

Estimation of the gains in size and biomass recorded with each treatment per locality: Table 3 indicates that in Dang, the best gain in size was recorded in the plots having received T1 treatment, followed by T3 treatment, respectively +47.32 cm and +39.49 cm compared to the control. In Touboro, it is also with T1 (+ 25.85cm) and T3 (+21.26 cm) treatments that the best size gains were recorded, unlike the results obtained with T4 (+17.13 cm) and T2 (+18.94 cm) which are less. In Bitcharé the highest gain is that of T1 treatment (+29.30 cm) and the lowest that of T2 treatment (+11.72 cm). Concerning biomass, the best gain was recorded in plots that received T1 treatment (+ 217.46g); conversely, the data obtained with the T4 treatment (+ 71.42g) is lower. In the locality of Touboro, the gains vary between +153.31 and + 241.05g, in particular, the highest values are those of the plots inoculated with the T1 treatment and the lowest those inoculated with the T4 treatment. The data obtained with T2 (+217.88) and T3 (+197.22 g) are intermediate. In Bitcharé, T1 (+ 166.12g) shows the best gain, while T2 (+ 59.59g) shows the lowest.

Table 3: Summary of the gains in size and biomass with each treatment by locality

Treatments	Sizes			Biomass		
	Dang	**Touboro**	**Bitcharé**	**Dang**	**Touboro**	**Bitcharé**
T0	/	/	/	/	/	/
T1	47,32	25,85	29,30	217,46	241,05	166,12
T2	23,95	18,94	11,72	169,44	164,9	59,59
T3	39,49	21,26	21,17	197,22	217,88	148,97
T4	24,06	17,13	21,34	71,42	153,31	129,79

Overall effect of each treatment on soybean growth in the three regions: Figure 4 illustrates the variation in the overall effects of each treatment on soybean growth in the three regions. It emerges from this figure that all four treatments have a similar overall performance in improving size and biomass in agro-ecological zones 1 and 2 of Cameroon; they show a similar aptitude for environmental adaptation indicating that it is the particular conditions of each locality which significantly affect their effectiveness.



Sizes: P= 0.1827, F = 2.4; Biomass: P = 0.1155, F = 2.72.

Figure 4: Overall effects of the four treatments on soybean growth in the three regions

Pods yield 90 days after sowing: Variable responses of soybean plants depending on the treatments were recorded in each locality (Table 4). Thus, in Dang, it was the T1 (27 ± 2) and T3 (27 ± 2) treatments which induced a better increase in the number of pods, unlike the T4 treatment (18) which showed a weaker performance. The number of pods is significantly higher in the plots having received the T1 treatment (45 ± 3) in Touboro, followed by the T3 treatment (42 ± 4), while T4 (38 ± 4) shows the lowest value in this locality. In Bitcharé on the other hand, T1 (22 ± 3) shows a better performance to induce an improvement of pods number, followed by treatments T4 (21 ± 3c) and T3 (21 ± 2) which are the same, T2 (14 ± 2) shows the lowest performance in this locality. For the pod weight, its value was more strongly improved in Dang at the level of the plots inoculated with T1 treatment (67±3g), and more weakly in those treated with T4

(54.4 ± 3) compared to the other treatments, (P = 0.0000). In Touboro, no significant difference was observed between the effects of T2 (37 ± 1.5), T4 (38.11 ± 1) and T0 (34.5 ± 3) treatments; on the contrary, the T1 treatment (50.12 ± 2) induced a significant increase in pod weight in this locality compared to the control (p = 0.0007), followed by T3 (41.11 ± 4). In Bitcharé, it was the treatments T1 (27.2 ± 0.15) followed by T3 (23.2 ± 0.71) which had a better improving effect on the number of pods. The values obtained with the T2 treatment (16.5 ± 0.17) is the lowest (P = 0.0000).

Table 4: Effects of treatments on pod yield 90 days after sowing

	Pods numbers			Weight		
Treatments	**Dang**	**Touboro**	**Bitcharé**	**Dang**	**Touboro**	**Bitcharé**
T0	7±2a	35±1a	9±2a	39±3a	34,5±3a	10,7±0,87a
T1	27±2d	45±3e	22±3d	67±3e	50,12±2c	27,2±0,15d
T2	25±3c	40±2c	14±2b	60,4±4c	37±1,5a	16,5±0,17b
T3	27±2d	42±4d	21±2c	61,9±4d	41,11±4b	23,2±0,71cd
T4	18±4b	38±4b	21±3c	54,4±3b	38,11±1a	22,4±0,91c
P-values	**0,0000**	**0,0403**	**0,0002**	**0,0000**	**0,0007**	**0,0000**
F-value	**29,68**	**3,77**	**16,15**	**29,57**	**12,38**	**304,40**

Values followed by the same letter are not significantly different at the 5% probability level.

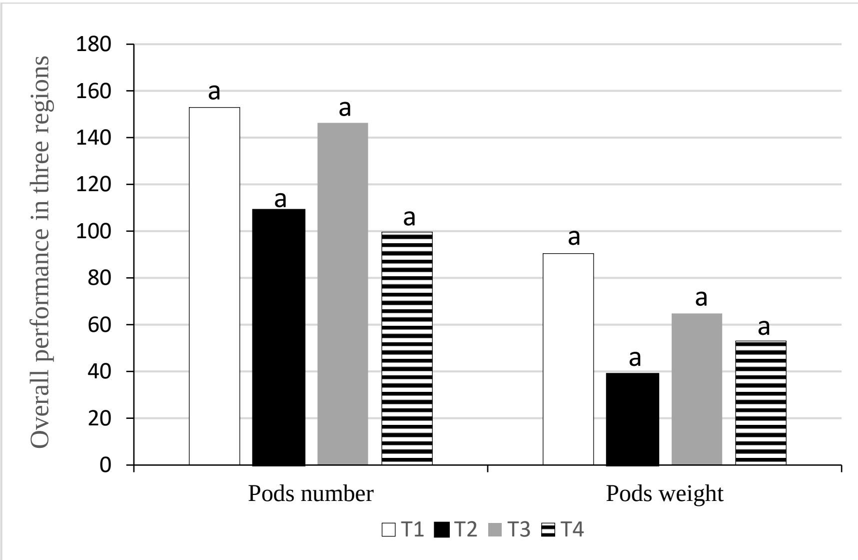
Effectiveness of each treatment on pod yield: The performance of each treatment in improving the pod yield of soybean plants varies depending on the locality (Table 5). In Dang locality, the benefits in terms of increasing the number of pods fluctuate between +157.14 and +285.71 compared to the control. In particular, the highest improvement values were observed with the T1 (+285.71) and T3 (+285.71) treatments and the lowest with the T4 treatment (+157.14). This same trend is observed in Touboro where the T1 treatment (28.57) showed better performance in improving the pod number of soybean plants and T4 (8.57) recorded the lowest improvement value. In the locality of Bitcharé, the T1 treatment (144.44) shows the greatest improvement in the number of pods, followed by T3 (133.33) and T4 (133.33). T2 treatment (55.55) presents the lowest value.

The best pod weight gain in Dang was that of the T1 treatment (71.79), while T4 (39.48) showed the lowest value. Similar observation was noted in Touboro where treatment T1 (45.27) recorded the greatest increase in pod weight followed by T3 (19.15). The data obtained with T2 (7.24) are weaker. The pod weight gain is higher in Bitcharé at the level of plots inoculated with T1 (154.2), lower on plots inoculated with T2 (54.20), intermediate with T4 (109, 34) and T3 (116, 82).

Table 5: Summary of the gains in number and weight of pods with each treatment per locality

	Pods number			Pods weight		
Treatments	**Dang**	**Touboro**	**Bitcharé**	**Dang**	**Touboro**	**Bitcharé**
T0	/	/	/	/	/	/
T1	285,71	28,57	144,44	71,79	45,27	154,2
T2	257,14	14,28	55,55	54,87	7,24	54,20
T3	285,71	20	133 ,33	58,71	19,15	116,82
T4	157,14	8,57	133,33	39,48	10,46	109,34

Effectiveness of each treatment in all three regions: Figure 5 indicates that there is no significant difference between the overall performance of each treatment on the number and weight of pods. This observation suggests that the environmental adaptation capacities of the different formulated treatments are similar.



Number of pods: P = 0.9510, F = 0.11; Pod weight: P = 0.61, F = 0.64

Figure 5: Effectiveness of each treatment in all three regions

Effects of the four treatments on seed yield: The seed yield varied significantly with the four treatments (P≤0.05) in the different localities (Table 6). All the four treatments significantly boosted the seed number of soybean plants in Dang locality. The treatment T1 (160 ± 3), followed by T3 (140 ± 4) proved to be more efficient while T4 (120 ± 2) and T2 (130 ± 32) showed a significantly lower performance, (P = 0.0000). In Touboro, it is always with the T1 treatment (310 ±13) that the greatest improvement in seeds number is recorded, conversely the performance of T4 (260 ± 3) is lower. In Bitcharé, the behaviours of the four treatments are similar to those observed in the other two localities. In fact, soybean plants inoculated with treatment T1 (140 ± 2), followed by T3 (120 ± 2), show significantly higher seed counts compared to other treatments. The value obtained with T2 (40 ± 2) is the lowest, (P = 0.0000). Regarding the weight of the seeds, in Dang the data observed with T1 (58 ± 3) and T3 (54 ± 5) are similar and significantly higher compared to T2 (48 ± 4) and T4 (38 ± 2), T4 being the lowest, (P = 0.0000). In the locality of Touboro, all the four treatments significantly increased the seed weight of the soybean plants. In particular, the highest weight is that obtained with the T1 treatment (31.4 ± 0.1); conversely, the weights obtained with the T3 (20.9 ± 0.1), T2 (20 ± 0.4) and T4 (21.3 ± 1.5) treatments are similar, (P = 0.0000). For Bitcharé, it was T1 (43 ± 3) which was more efficient while T4 (24 ± 4) and T2 (20 ± 2) are the same and weaker, (P = 0.0001).

Table 6: Effects of treatments on seed yield in each locality

	Seeds number			Seeds Weight		
Treatments	**Dang**	**Touboro**	**Bitcharé**	**Dang**	**Touboro**	**Bitcharé**
T0	70±2a	220±10a	20±2a	14±3a	10,3±0,5a	13±7a
T1	160±3e	310±13e	140±2e	58±3d	31,4±0,1c	43±3d
T2	130±3c	270±13c	40±1b	48±4c	20±0,4b	20±2b
T3	140±4d	280±10d	120±2d	54±5d	20,9±0,1b	31±5c
T4	120±2b	260±3b	90±2c	38±2b	21,3±1,5b	24±4b
P-values	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0001**
F-value	**25,56**	**403,57**	**2311,76**	**73,52**	**312,74**	**19,03**

Values followed by the same letter are not significantly different at the 5% probability threshold.

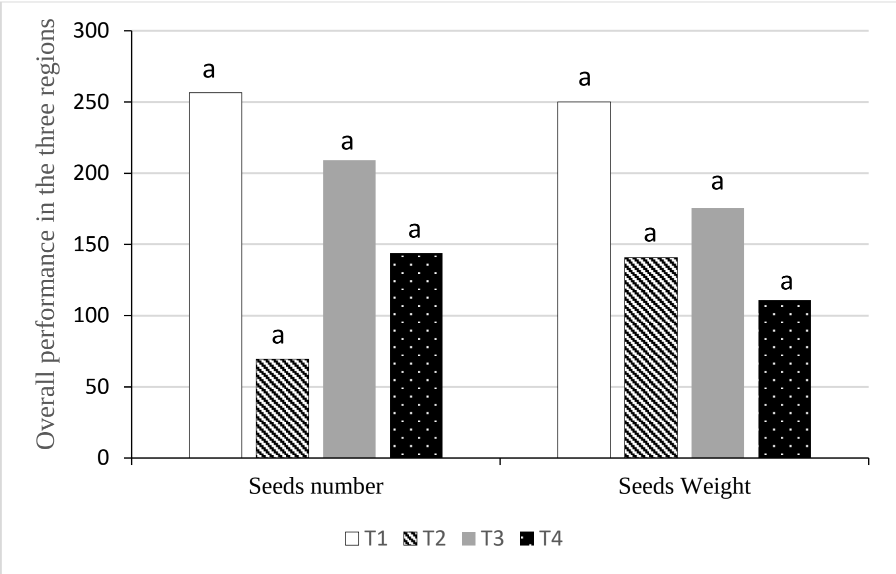
Effectiveness of each treatment on seed yield in each locality: The effectiveness of treatment on the number and weight of seeds varies within and between localities (Table 7). For the number of seeds, the best benefit obtained in Dang is from T1 treatment (+128.57), while the lowest gain is from T4 treatment (+71.42). In Touboro, it is always the T1 treatment (+40.9) which shows the best gain in seeds number, and the lowest gain is observed with the T4 treatment (+10.18). The same trend is observed in the locality of Bitcharé, where the number of seeds recorded with the T1 treatment (+600) is significantly higher than the other treatments and the lowest is that of the T4 treatment (+350). The seed weight is better with T1 treatment (314.28) in Dang; it is lower with the T4 treatment (171.42) in this locality. T1 (204.85) still shows better performance at Touboro to improve seed weight. While it is always T2 treatment (94.17) which shows the weakest performance in this locality. The observation is similar in Bitcharé, where the gain in seed weight is greater in soybean plants inoculated with T1 treatment (230.76) and lower in those having received T4 treatment (53.84).

Table 7: Summary of the gains in number and weight of seeds with each treatment by locality

	Seeds number			Weight number		
Treatments	**Dang**	**Touboro**	**Bitcharé**	**Dang**	**Touboro**	**Bitcharé**
T0	/	/	/	/	/	/
T1	128,57	40,9	600	314,28	204,85	230,76
T2	85,71	22,72	100	242,85	94,17	84,61
T3	100	27,27	500	285,71	102,91	138,46
T4	71,42	10,18	350	171,42	106,79	53,84

Effectiveness of each treatment in all the three regions: Figure 6 shows that no significant difference is observed when comparing the overall effects of the four treatments in all three localities, both for the improvement of the number of seeds (P =

0.6989, F = 0,49), and the weight (P = 0.9332, F = 0.14). This reflects the similarity of adaptability of the different treatments in agro-ecological zones 1 and 2 of the Cameroon study.



Number of seeds: P = 0.74, F = 0.42; Seed weight: P = 0.22, F = 1.8.

Figure 6: Effectiveness of each treatment in all three regions

Effects of the four treatments on the yield per hectare of soybean plants: The variation in the yield per hectare of the soybean plants between the treatments according to the localities is presented in table 8. In Dang, the plants of the plots having received T1 treatment (870 ± 5kg) show a better seed yield per hectare, followed by those inoculated with T3 (780 ± 10 kg). T2 (570±3kg) shown a lower performance. In Touboro, it is always the T1 treatment (410 ± 10kg) which has the highest yield per hectare follows by the value recorded with T3 (313 ± 13b). The one registered with T2 (309 ± 6) and T4 (309 ± 15) are the same, (P = 0.0000) and lower. The observations follow the same trends at Bitcharé, where the value of the yield per hectare obtained with T2 (225 ± 4kg) is significantly (P = 0.0000) lower compared to the others treatments, and it is also the T1 (695 ± 4ktg) which shows the best performance.

Table 8: Effects of the four treatments on the yield of soybean plants per hectare

	Yeld per hectar		
Treatments	**Dang**	**Touboro**	**Bitcharé**
T0	330±15a	271±13a	195±10a
T1	870±5e	410±10c	695±4e
T2	675±10c	309±6b	225±4b
T3	780±10d	313±13b	465±13d
T4	570±3b	309±15b	405±6c
P-values	**0,0000**	**0,0000**	**0,0000**
F-values	**1426,47**	**57,74**	**2072,35**

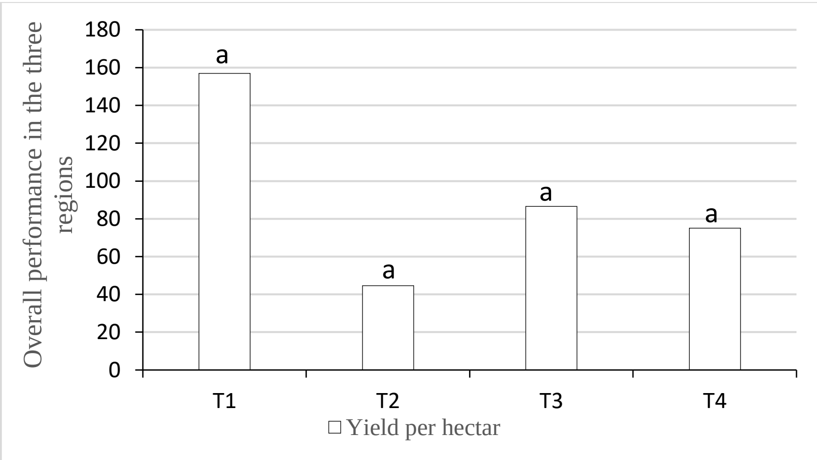
Values followed by the same letter are not significantly different at the 5% probability level.

Gains in terms of seed yield per hectare with each treatment by locality: The benefits in yield per hectare induced by each treatment are summarized in Table 9. The improvements recorded at Dang fluctuate between +72.72 and +163.63. It is the plots where the T1 treatment (+163.63) was applied that presented a better yield per hectare, while those which received the application of the T4 treatments (+72.72) showed a weaker benefit. In Touboro, it was also with T1 (+51.29) that the best gain was observed. The profits recorded with T2 (+14.2) and T4 (+14.2) are the same and lower. The trends are similar in Bitcharé where the lowest gain is observed with the T2 treatment (+15.38) and the strongest with the T1 treatment (+256.41).

Table 9: Summary of yield gains per hectare with each treatment by location

	Rendement à l'hectare		
Treatments	**Dang**	**Touboro**	**Bitcharé**
T0	/	/	/
T1	163,63	51,29	256,41
T2	104,54	14,02	15,38
T3	136,36	15,49	107,69
T4	72,72	14,02	138,46

Effectiveness of each treatment on yield per hectare in the three regions: Figure 7 reveals that the overall performance of the four treatments on the yield per hectare in the two agro-ecological zones (three regions) are not significantly different (P = 0.9330). No treatment exhibits a particular adaptability in all the three regions.



P=0.3427, F=1.29

Figure 7: Effectiveness of each treatment on yield per hectare in all three region

DISCUSSION

The objective of the inoculation of soybean plants with indigenous mycorrhizal fungi strains is to establish an adequate symbiosis by providing the roots of the plants with fungi capable of providing them with additional growth and nutrition. The results of the present work establish that all the four mycorrhizal treatments (T1, T2, T3 and T4, better performance with T1 and T3) induce an increase in the size and biomass of the plant under investigation and the results recorded vary according to the localities. For height, the values recorded vary between 29.45 - 55.1 cm, with a gain fluctuating between + 11.72 and + 47.32% cm compared to the control. For biomass, the data observed range from 3.91 ± 0.5g to 16 ± 2.13g, for a gain varying from 59.59 - 217.88% compared to the control. These observations are similar to those of Ngakou e*t al.* (2007) who reported increases in size varying between 17-46% while working on the effect of commercial arbuscular mycorrhiza fungi on cowpea in the 5 agro-ecological zones of Cameroon, Ogou *et al*. (2018) who observed an increase in the height of soybean plants inoculated with mycorrhiza in Togo with a benefit varying between 14-32 cm. These results are superior to those of Ngakou *et al*. (2020) who recorded height increases ranging from 4.85 cm to 6.28 cm in a study analysing the response in pot condition of garlic (*Allium sativum*) to mycorrhizal inoculation. The increase in biomass is also higher compared to the results of Haro *et al*. (2015) who obtained improvements of less than 2g when evaluating the response of cowpeas to mycorrhizal inoculation in Burkina Faso. Regarding the pod yield, the improvements induced by the effect of the different treatments are between 14 and 45 pods, for benefits varying between 8.57 - 285.71%; concerning pods weight, 10.7 ± 0.87g to 61.9 ± 4g for benefits compared to the control ranging from + 7.24g to + 154.2g. These observations are similar to those of Ogou *et al*. (2018) who obtained in Togo an average gain in pods induced by mycorrhizae on soybeans of + 126.83% compared to the control. Moussa *et al*. (2018) reported average improvement of 23.4% induced by mycorrhizal inoculation in *Vigna subterranea*. Regarding seed yield, the lowest values recorded are 20±2 and the highest 310±13 for seeds number, with a benefit compared to the control between +10.18 and +200; These seeds have a weight which fluctuates between 58 ± 3g and 20 ± 2g, whith a gain compared to the control varying between + 53.84g and + 314.28g. Hemissi *et al*. (2019) in Tunisia, obtained a gain of 5 seeds more than the control. For the yield per hectare, the estimated values are between 225 ± 4kg and 870 ± 5kg, for a benefit compared to the control varying between +14.02 kg and + 256.41kg. Hemissi *et al*. (2019) in Tunisia, obtained a gain of 20 kg/ha of wheat more than the control. The overall performance of the four treatments in all three localities located in the three regions is not significantly different on the various soybean agronomic parameters, sizes, biomass, pod yield, seed yield and yield per hectare. This similarity can be justified by the fact that they are indigenous strains, and therefore naturally adapted to this environment. And it is rather the chemical properties of each locality that induce variation in their effectiveness. These improvements in soybean growth and yield by arbuscular fungi are explained by the fact that mycorrhizae degrade and mineralize organic matter in the soil, and mobilize the resulting nutrients for the benefit of the plant (2008). In addition, mycorrhizae develop extra-radical mycelial hyphae which explore a larger volume of soil not accessible to plant roots (Clark R. B. & Zeto S. K., 2000). The plant's mineral (in particular phosphorus) and water nutrition is therefore significantly boosted. In return, the plant provides the fungal partner with habitat and carbohydrates that it elaborated through photosynthesis process. The variation of soybean response depending of the treatments shows that there is a plant-arbuscular fungi preference or an ecological preference of arbuscular fungi / host plant symbiosis (McGonigle T. P., Fitter A. H., 1990). A possible explanation of the variation in the effects of treatments depending of the locality may be related to the diversity of the cultural practices that take place in each locality, in particular ploughing, crop rotation, chemical fertilization, the use of phytosanitary products which influence significantly arbuscular fungi (Oehl et al., 2003 ; Kabier Z., 2005).

CONCLUSION AND APPLICATION OF RESULTS

The main objective of this work was to evaluate the response of soybean to endomycorrhizal inoculation in the three northern regions of Cameroon. The fungal inoculums were composed of specimens of arbuscular fungi native to the soybean rhizosphere in the study area. After extraction and multiplication of the spores, four different treatments were formulated: T1, T2, T3 and T4. Tests were conducted in three different fields, Dang in the Adamaoua region, Touboro in the North region and Bitcharé in the Far North region in order to assess the effect of these treatments on the growth and yield of soybeans. Analysis of the results after 90 days of growth showed that all treatments boosted the growth and yield of the soybeans. T1 and T3 treatments performed better in increasing size, biomass, pod number, pod weight, seed number, seed weight and yield per hectare. The results obtained with the T2 and T4 treatments are weaker. T1 and T3 can be recommended to promote ecological soybean production in the northern regions of Cameroon. Our results indicate that the endogenous arbuscular mycorrhiza from soybean rhizosphere, especially the mixture of native spores of the three northern regions (T4) or those isolated on Adamawa region (T1) soils can effectively boost growth and yield of soybean plant. Thus, this technology can be popularized in Cameroon to market bio-fertilizers, less expensive, efficient and ecological.

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