

## Improving sorghum (*Sorghum bicolor* L.) production through by the using of *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4-based biostimulants

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### ABSTRACT

**Objectives/Aims:** The objective(s) aim of the present work experiment was to evaluate the effect of *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4-based biostimulants formulated in Mali, on the growth and yield of Sorghum in Mali field in Mali, in during monsoon/rainy season.

**Study design:** The experimental was conducted design was in a completely randomized block design with three treatments, four replications, and three treatments randomly distributed. The blocking factor was the direction of rainwater runoff.

**Place and Duration of Study:** The trials were conducted in the rural commune of Oueléssebougou, located 80 km south of Bamako. The commune is located in the Sudanian climate zone with an annual rainfall of 600 mm to 1100 mm, but exceeds 900 mm.

**Methodology:** The study was carried out in the rural commune of Oueléssebougou located in the Sudanian climate zone with an annual rainfall of 600 mm to 1100 mm, but exceeds 900 mm. The sorghum seeds inoculated or non-inoculated seeds with *Azospirillum* sp. AZ6, *Trichoderma harzianum* T4, were randomly sown in single-cropped with no nitrogen (N) application. For the control, 100% of the dose of Nitrogen was applied at sowing time at a dose of 120 kg ha<sup>-1</sup> N. Sorghum plant height, sorghum yield, number of panicles and the weight of 1000 grains weight were evaluated.

#### Results:

The salient findings results obtained showed a significant increase of the parameters examined by that *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4-based biostimulants increased significantly all parameters. Inoculation of AZ6 improved sorghum yield by 68,25%, while T4 by 8.73% in comparison to with the control.

**Conclusion:** It is evident that the present work specify that, *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4 are suitable for inoculating on sorghum (*Sorghum bicolor* L.). *Azospirillum* sp. AZ6-AZ6 produced the the highest plant height, yield, number of panicles, and 1000 grain weight relative to, when compared to *Trichoderma harzianum* T4 and the non-inoculated control. Therefore, this suggest that *Azospirillum* sp. AZ6-AZ6 is suggested for is suitable for large scale application in sorghum fields application, which may to reduce the production costs and, by increasing sorghum yield while reducing Nitrogen fertilizer application rate.

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The structure of the abstract should be as follows; **objectives**, **methodology** (including the design of the study, place and duration, the treatment description), **results** and **conclusions**.

### 1. INTRODUCTION

In Sahelian countries, such as Mali, Niger, Burkina Faso and Senegal, the basic diet of the populations is of cereal origin [1]. Sorghum is one of the main cereals consumed in the Sahel, is the fifth most cultivated cereal in the world including Sahel, after maize, rice, wheat and barley [2], [3], [4]. In the poorest areas where food security is threatened, sorghum is a commodity sought after in human food, mainly for its starchy, sweet and fructose-rich grains [5] [6]. Sorghum fodder is also used in livestock feed [7]. World sorghum production is 58,705,915 tonnes on an area of approximately 40,251,818 ha with an average yield of 1,458.5 kg/ha [8]. Production in the Western Africa is 13,648,844 tonnes on an area of 14,025,233 ha, i.e. a

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yield of 973.2 kg/ha [8]. In Mali, sorghum production was 1,801,017 tonnes for an area of 1,831,825 ha with an average yield of 983 kg/ha [9]. Sorghum constitutes 35% of dry cereal production [10]. *Sorghum* cultivation is characterized by low production due to biotic and abiotic constraints including: insufficient and poorly distributed rainfall, low soil fertility, low production potential of so-called local varieties, the sensitivity of certain varieties to insect pests, weeds, a wide range of diseases and generally unfavorable socio-economic conditions [11], [12], [4].

The use of chemical fertilizers to increase production has led to contamination of groundwater and surface water, harming fish and wildlife. This has led to increased agricultural dependence on fossil fuel resources. It is therefore necessary to develop an effective alternative method to sustainably improve agricultural production while reducing the use of chemicals that have shown their limitations [13]. Research has been conducted in recent years on the use of soil microorganisms, mainly rhizosphere microorganisms capable of improving plant growth (MFCP) or Plant Growth Promoting Microorganisms (PGPM) (Plant Growth Promoting Microorganisms) in English. The several findings of other results of the work of several researchers around the globe have demonstrated that the use of these rhizosphere microorganisms as bio-fertilizers, constitutes a credible alternative to the use of chemical fertilizers. The *Azospirillum* genus is generally used to improve the mineral nutrition of plants [14], while the *Trichoderma* genus fungus is used to stimulate plant growth and protect them against a wide range of phytopathogens [15], [16], [17]. The use of PGPM-based bioinoculants can be considered as a means to minimize the adverse effects of biotic and abiotic constraints and this aid to transition towards a sustainable agricultural production system [18]. Thus, the present investigation was implemented study therefore aims to (i) formulate biostimulants based on *Azospirillum* sp. Az6 and *Trichoderma harzianum* T4 and (ii) determine the effects of biostimulants on the growth and production of sorghum in the fields.

## 2. MATERIAL AND METHODS

### 2.1 Study Site Description

The study trials were conducted in the rural commune of Oueléssebougou. The commune is composed of 45 villages and is located 80 km south of Bamako. It covers an area of 1,117 km<sup>2</sup>. It is bordered to the north by the commune of Dialakoroba, to the south by the commune of Kéléya, to the east by the commune of Sanakoro-djitoumou and to the west by the commune of Faraba. The climate of this commune is semi-arid, characterized by heat, with two major seasons: a dry season that runs from November to April and a rainy season that extends from May to October. The commune is located in the Sudanian climate zone with an annual rainfall of 600 mm to 1100 mm, but exceeds 900 mm. The relief is monotonous overall with altitudes between 90 m and 100 m. The vegetation consists of shrub savannah.

### 2.2 Material(s)

#### 2.2.1 Biological material

##### 2.2.1.1 Plant material

The seeds of the SOUBA TIMI variety, used during the trial, were kindly donated by Dr. Aboubacar Touré de dit Akar, researcher at ICRISAT. The variety has a cycle of 120 days with a potential yield of 3t/ha and a weight of 1000 seeds of 23.7 g. It is a dual-use variety: the grain is mainly for human consumption and fodder for livestock feed. It is possible to produce

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this variety in the off-season. It is also a variety called stay green, a variety useful for drought resistance [19].

### 2.2.1.2 Microorganisms

Two strains from the LaboREM-Biotech collection were used during the trial. These are: *Trichoderma harzianum* T4 (fungus) and *Azospirillum* sp. Az6 (Bacteria).

## 2.3 Methods

### 2.3.1 Production of biostimulants

#### 2.3.1.1 Culture of *Azospirillum* sp. Az6 and *Trichoderma harzianum* T4

*Azospirillum* sp. was sub-cultured on a specific medium (Nutrient Agar) and incubated at 30°C for 48 hours; The *Trichoderma harzianum* strain was also sub-cultured on potato dextrose agar (PDA) medium followed by then incubated in BOD at 25°C for seven (7) days.

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#### 2.3.1.2 Production of *Trichoderma harzianum* T4 inoculum

The fungal inoculum (*Trichoderma harzianum* T4) was prepared by producing a homogeneous mixture of mycelial and spores of the fungus in 9 mL of sterile distilled water. One hundred (100) µL of this solution were spread on PDA medium, and incubated for 7 days at 25°C. After incubation, the spores were recovered and transferred to a bottle containing 500 ml of sterile distilled water [20]. Before use in the fields, the sorghum seeds were coated with the spores for 24 hours. After the mixture of charcoal and gum arabic was added [21].

#### 2.3.1.3 Production of *Azospirillum* sp. inoculum. AZ6

The bacterial inoculum (*Azospirillum* sp. AZ6), it was taken to inoculate the nutrient broth and stirred for 72 hours at 200 rpm. After incubation the optical density of the bacterial suspension was adjusted to 108 cfu / ml. Before sowing, the sorghum seeds were sanitized using 2% chloramine T and soaked in the bacterial solution for 60 minutes [22].

### 2.3.2 Experimental design

To determine the effect of the strains (treatments) on sorghum, we used a completely randomized block design with 4 blocks and three treatments (T<sub>1</sub>: Control; T<sub>2</sub>: coated with *Azospirillum* sp. AZ6, and T<sub>3</sub>: coated with *Trichoderma harzianum* T4) was used, randomly distributed randomly between the blocks. The blocking factor was the direction of rainwater runoff. The experimental unit was an elementary plot of 4.8 m x 4.8 m or 23.4 m<sup>2</sup>. The distance between the blocks was 1 m, the distance between the plots was 1 m and the distance between the pockets was 0.80 cm.

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#### 2.3.2.1 Sowing

Sowing was achieved carried out on the 17<sup>th</sup> July 17, 2022 using the hand at a rate of 5 to 10 seeds per pocket on the 12 elementary plots for the treatments. Before planting the crops, the seedbed was prepared by shallow plowing (30 cm deep). Sowing was carried out by hand at a rate of 5 to 10 seeds per pocket on the 12 elementary plots for the treatments. The Fifteen 15 days after sowing (DAS), thinning was done at the a rate of 2 plants per pocket, followed by a first weeding using the daba. A second weeding was carried out 30 DAS of sorghum days after sowing.

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#### 2.3.2.2 Monitoring and collection of agronomic parameters

To evaluate the effect of biostimulants on sorghum, the following agronomic parameters were considered taken into account: the plant size, number of panicles, yield and weight of 1000 grains. Plant heights in cm. All the measurements of the different parameters were carried out on a sample of five (5) plants taken at random for the first time per treatment and repetition: Az6 (Five plants), Th (Five plants), Th T<sub>4</sub> (Five plants), Control (Five plants). The five plants of each elementary plot were identified and referenced for the following measurements.

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**2.3.2.2.1** The number of panicles per treatment

With regard to Concerning the number of panicles per treatment (AZ6, T4, Control) it was counted after harvesting in the field and this at each of the four repetitions.

**2.3.2.2.2** Yield of each treatment in grams

To calculate the yield for each treatment (AZ6, T4, Control), the weight of the harvested seeds was determined by weighing in an using an electronic balance scale. Before obtaining determining the total weight and the weight of 1000 seeds by weighing, the moisture content was estimated determined for each treatment using a moisture meter.

**2.3.2.2.3** Grain size:

The weighing of grain was done after destoning the weight of 1000 seeds for each treatment was weighed and this was repeated three times to take the average. In the process, 1000 seeds were first counted using a counting device (CONTADOR Type: PFEUFFER). An electronic balance was then used to determine the weight of the 1000 seeds.

**2.3.2.3** Statistical analysis of data collected in the field

The homogeneity of variance was verified for all data collected. Non-homogeneous data were transformed before analysis. The analysis (ANOVA) analysis for the different agronomic parameters examined measured was done for all the data using the procedures of the General Linear Model (GLM) procedures of the Statistical Analysis System (SAS). For all parameters whose F-calculated value was found to be significant, the means were compared using the least significant difference (LSD) test protected as given by Fischer [23].

#### Ethical considerations

The strains *Trichoderma harzianum* T4 and *Azospirillum* sp. Az6, do not constitute dangers for human health, even less for the environment [24], [25].

### 3. RESULTS AND DISCUSSION

#### 3.1 Biostimulants formulated with *Trichoderma harzianum* T4 and *Azospirillum* sp. AZ6

The biosinoculants based on *Azospirillum* sp. AZ6 and *Trichoderma harzianum* were produced and used to inoculate sorghum seeds using charcoal powder as a carrier and a cassava powder solution as an adhesive (Figure 1 A, B, C)



**Figure 1.** Coating of sorghum seeds with the formulated bio-stimulants: (A) Inoculum of *Azospirillum* sp. Az6, (B) sorghum seeds coated with *Azospirillum* sp. AZ6, and (C) sorghum seeds coated with *Trichoderma harzianum* T4.

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### 3.2 Effect of the *Azospirillum* and *Trichoderma*-based biostimulants on sorghum growth and production

The inoculation of sorghum (*Sorghum bicolor* L.) seeds with bio-stimulants formulated with *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4, all isolated in Mali, has significantly enhanced plant height, yield, number of panicles and 1000 grain weight of sorghum (Table 1). However, the rate of enhancement varied significantly with the treatments. The *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4 bio-inocula were observed to have significantly increased the height, the yield, the number of panicles, and the 1000 grain weight of the sorghum significantly over the (control) non-treated control. The significantly highest values of height, yield, number of panicles, and 1000 grains weight of sorghum cultivated in field were recorded under with *Azospirillum* sp AZ6, followed by *Trichoderma harzianum* T4 (Table 2 and Figure 2).

Table 1:- Analysis of variance for plant height, yield, number of panicles and 1000 grains weight of sorghum (*Sorghum vulgare*) under cultivated field conditions.

Sources of variation	DF	Mean square			
		Plant height (cm)	Yield (T/ha)	Panicles number	1000 seeds weight
Treatments	2	967,80***	0,12***	180,10***	17,54***

DF: Degree of freedom, \*Significant, \*\*Very significant, \*\*\*Highly significant

Table 2:- Effect of bio-inoculants formulated with *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4 on the height, the yield, the number of panicle, and the 1000 grain weight of sorghum (*Sorghum vulgare*) under cultivated field conditions.

Treatments	Height (Cm)	Yield (T/ha)	Number of panicles	1000 grains weight (G)
<i>Azospirillum</i> sp. AZ6	159.26	2.12	67.17	23.98
<i>Trichoderma harzianum</i> T4	155.62	1.37	55.12	22.08
Control	138.65	1.26	46.02	20.15



**Figure 2.** A comparison of Photos of sorghum ears inoculated with *Azospirillum* sp. Az6 and *Trichoderma harzianum* T4 and compared to the control

#### 4.3.2 Discussions

In this study, the results obtained showed that *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4-based biostimulants increased significantly Sorghum plant height, number of panicles, yield and weight of 1000 grains. The inoculation of *Azospirillum* sp. AZ6, significantly increased Sorghum plant height and improved its yield by 68,25% relative to compared to the control. Indeed, [26] showed that the use of *Azospirillum* sp. AZ6 strain, applied used in this study was found to have significantly improved significantly maize plant growth, yield and the weight of 1000 grains by producing Indole Acetic Acid (IAA), siderophores and fixing atmospheric nitrogen which is well-known to have a direct effect on plant growth [26]. It was further observed that a significant increase of 20% in maize plant height was obtained while employing them in field with *Azospirillum* sp. AZ6 an increase of 20% in maize plant height in comparison with the control (non-inoculated maize seeds) control. [22] reported an improvement in maize plant height by 44% and yield by 21.3% was also reported [22], even though the results which were lower than those of the present study obtained in this study. These differences may be due to the quality of cereal used as the because tests were performed under different field conditions. In the same way, Lynch et al. [27] demonstrated that the inoculation of *Azospirillum brasilense* allows a higher index of chlorophyll a and b, and the development of the aerial part of the sorghum, thus increasing the specific surface area (SSA) of sorghum roots compared to with non-inoculated plants grown only with nitrogen fertilization in the soil contaminated with copper.

Earlier findings, [20] [28] [29] showed an improvement in plant productivity due to the growth-stimulating activity of *Trichoderma harzianum* [20: 28-29]. In dry climatic conditions in the off-season as in the current study, Wei et al. [30] obtained a significant increase in yield, after the inoculation of sorghum seeds cv. Ranchero with *Azospirillum brasilense*. Similarly, in the same way, Cabral-Miramontes et al. [31] announced that the *Trichoderma harzianum* T4 strain was capable of increasing the germination rate and advancing maize growth of maize and rice, mainly by effectively controlling of pathogenic fungi and production of growth promoting substances. Dabire et al. [32] reported a significant increase on sweet sorghum plant height, and its growth under saline conditions promoted by *Trichoderma* inoculation through regulation of available nutrients and the field tests demonstrated, showed an outstanding capabilities to adapt to alkalinity stress as evidenced by the present study. These have also shown antagonistic activity against three

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phytopathogenic fungi. Additionally, the [strains](#) provided evidence of significant growth promotion in *Sorghum bicolor* [\[33\]](#) in Burkina Faso who obtained an [an](#) improvement in plant height ranging from 19.75% to 33.33% on six varieties of maize inoculated with *Trichoderma harzianum* in Burkina Faso [\[33\]](#). The *Trichoderma harzianum* strains [significantly](#) increased sorghum yield by 0.52% [\[33\]](#) and this is lower (15.69%) than the one obtained in maize yield. The results were not attained by [33](#) with 15.69%. These differences can be explained by the non-use of the same crop and the same agro-ecological conditions of the study areas.

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#### 4. CONCLUSION

The present studies specify that, *Azospirillum* sp. AZ6 and *Trichoderma harzianum* T4 were suitable for inoculation [ong](#) on sorghum (*Sorghum bicolor* L.). *Azospirillum* sp. AZ6 produced the highest plant height, yield, number of panicles, and 1000 grain weight, [when](#) compared to *Trichoderma harzianum* T4 and the [control](#) (non-inoculated) [control](#). Therefore, *Azospirillum* sp. AZ6 [canis be](#) suggested for large scale [application in the](#) sorghum fields [application, as which may to minimize reduce the](#) production costs, [by increasing the yield of](#) sorghum [yield while and ultimately](#) reducing [n](#) Nitrogen application.

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#### REFERENCES

- [1] FAOSTAT. 2017, <http://www.faostat.fao.org>
- [2]. Temple L, Levesque A, Lamour A, Charles D, Braconnier S. Complementarity of the sweet sorghum and sugarcane sectors in Haiti: assessment of the conditions for the sectoral development of an innovation. Cah. Agric. 2017, 26, 55006
- [3]. Smith O, Nicholson WV, Kistler L, Mace E, Clapham A, Rose P, ... Allaby RG. A domestication history of dynamic adaptation and genomic deterioration in Sorghum. Nature plants. 2019; 5(4), 369-379.
- [4]. Keita A. Study of the effect of sowing spacing in a variety of grain sorghum (*Sorghum bicolor* (L.) Moench) CE 180-33 with tannin for seed production in Haute Casamance (Senegal); 2019.
- [5]. Comas J, MacPherson H. Flood recession sorghum cultivation in West and Central Africa. Current situation and definition of a Regional Action Plan; FAO, 2002.
- [6]. Peerzada AM, Ali HH, Chauhan BS. Weed management in sorghum [*Sorghum bicolor* (L.) Moench] using crop competition: A review. Crop protection. 2017; 95: 74-80.
- [7]. Sawadogo N, Batiéno TJB, Kiébré Z, Ouédraogo MH, Zida WPMSF, Nanéma KR, Bationo-Kando P, Traore R, Sawadogo M, Zongo JD. Assessment of genetic diversity of Burkina Faso sweet grain sorghum using microsatellite markers. African Journal of Biotechnology 2018; 17(12), 389-395
- [8]. FAO. Analysis of incentives and penalties for millet and sorghum in Mali, 2020. <http://faostat.fao.org/site/Africa>
- [9]. FAO. FAOSTAT databases (Food and Agriculture Data). Rome. 2021b. [www.fao.org/faostat/en/#home](http://www.fao.org/faostat/en/#home) (accessed January 2022).
- [10]. Soumaré M. Contribution to the prediction of the diffusion area of sorghum varieties in Mali: coupling between crop growth model and geographic information system. 2004. Doctoral thesis. University of Paris-Nanterre.
- [11]. IRD. Sorghum: When agriculture rhymes with biodiversity. 2010; 2 pages
- [12]. Abdou MM., Mayaki ZA, Lamso ND, Seybou DE, Ambouta JMK. Productivity of sorghum (*Sorghum bicolor*) cultivation in an agroforestry system based on *Acacia senegal* (L.) Willd. in Niger. Journal of Applied Biosciences, 2014, vol. 82, pp. 7339-7346.

- [13]. Sharma A, Chetani R. A review on the effect of organic and chemical fertilizers on plants. *Int. J. Res. Appl. Sci. Eng. Technol*, 2017, vol. 5, p. 677-680.
- [14]. Gaskins M., Albrecht SL, Hubbell D.H. Rhizosphere bacteria and their use to increase plant productivity: a review. *Agriculture, ecosystems & environment*, 1985, vol. 12, no. 2, p. 99-116.
- [15]. Harman GE, Howell CR, Viterbo A, Chet I, Lorito M. *Trichoderma* species—opportunistic, avirulent plant symbionts. *Nature reviews microbiology*, 2004, vol. 2, no. 1, p. 43-56.
- [16]. Bais HP, Weir TL, Perry LG, Gilroy S, Vivanco JM. The role of root exudates in rhizosphere interactions with plants and other organisms. *Annu. Rev. Plant Biol.*, 2006, vol. 57, no 1, p. 233-266.
- [17]. Adams P, De-Leij FA, Lynch JM. *Trichoderma harzianum* Rifai 1295-22 mediates growth promotion of crack willow (*Salix fragilis*) saplings in both clean and metal-contaminated soil. *Microbial ecology*, 2007, vol. 54, p. 306-313.
- [18]. Bouzid A, Boudedja K, Cheriet F, Bouchetara M, Mellal A. influencing the adoption of innovation in agriculture in Algeria. Case of two strategic crops: durum wheat and potato. *Cahiers Agricultures*, 2020, vol. 29, p. 15.
- [19]. Dembele DM, Nebie B, Sidibe M, Diallo A, Toure A. Participatory evaluation process of new varieties in a farmer environment: case of sorghum in Mali. 2023. [20]. Diarra M, Kassogue A, Babana AH, Hamadoun O, Cisse F, Hamadoun A. Isolation and in-vitro assessment of antagonistic activity of *Trichoderma* spp. against *Magnaporthe oryzae* Longorola strain causing rice blast disease in Mali. *African Journal of Microbiology Research*, 2022, vol. 16, no. 2, p. 67-75.
- [21]. Dicko AH, Babana AH, Kassogu e A, Fan e R, Nantoum e D, Ouattara D, Dao S. A Malian native plant growth promoting Actinomycetes based biofertilizer improves maize growth and yield. *Symbiosis*, 2018, vol. 75, p. 267-275.
- [22]. Mall e I, Kassogu e A, Babana AH, Oliveira-Paiva CA, Marriel I. A Malian native *Azospirillum* sp. Az6-based biofertilizer improves growth and yield of both rice (*Oryza sativa* L.) and maize (*Zea mays* L.). 2020. [23]. Rgd S. Principles and procedures of statistics. A Biomedical Approach, 1980. [24]. Sarsaiya S, Jain A, Fan Forehead. *Microbiol.* 2020, 11, 337. [CrossRef] [PubMed] [25]. Jeyanthi V, Kanimozhi S. Plant growth promoting rhizobacteria (PGPR)-prospective and mechanisms: a review. *J Pure Appl Microbiol*, 2018, vol. 12, no. 2, p. 733-749.
- [26]. da Silva JC, da Silva RF, dos Santos VM, da Rocha Giovenardi A, da Silva DM, Canepelle E, da Silva AP. Plant growth-promoting bacteria in sorghum development in copper contaminated soil. *Revista Brasileira de Ci ncias +Ambientais (RBCIAMB)*, 2024, vol. 59, p. e1660-e1660.
- [27]. Lynch JM, Lumsden RD, Atkey PT, Ousley MA. Prospects for control of *Pythium* damping-off of lettuce with *Trichoderma*, *Gliocladium* and *Enterobacter* spp. *Biology and fertility of soils*, 1991, vol. 12, p. 95-99.
- [28]. Besnard O, Davet P. Observations on some *Trichoderma* spp strains that are simultaneously antagonistic to *Pythium ultimum* and growth stimulating. *Agronomie (France)*, 1993, vol. 13, no 5.

[29]. Soares DDA, Andreotti M, Nakao AH, Modesto VC, Dickmann L, Freitas LA. Inoculation with *Azospirillum* combined with nitrogen fertilization in sorghum intercropped with *Urochloa* in off-season. *Revista Ceres*, 2022, vol. 69, no 2, p. 227-235.

[30]. Wei Y, Yang H, Hu J, Li H, Zhao Z, Wu Y, Li J, Zhou Y, Yang K and Yang H. *Trichoderma harzianum* inoculation promotes sweet sorghum growth in the saline soil by modulating rhizosphere available nutrients and bacterial community. *Front. Plant Sci.* 2023, 14:1258131. doi: 10.3389/fpls.2023.1258131

[31]. Cabral-Miramontes JP, Olmedo-Monfil V, Lara-Banda M, Zúñiga-Romo ER, Aréchiga-Carvajal ET. Promotion of plant growth in arid zones by selected *Trichoderma* spp. strains with adaptation plasticity to alkaline pH. *Biology*, 2022, vol. 11, no 8, p. 1206.

[32]. Dabire TG, Ouologueme MY, Bonzi S, Somda I. (2023). Search for a suitable substrate for mass propagation of a local strain of *Trichoderma harzianum* (ThTab) isolated in Burkina Faso. *International Journal of Environment, Agriculture and Biotechnology*, 2023; 8(6): 156-166

[33]. Sawadogo J, Coulibaly PJ, Traore B, Bassole MSD, Kabore A, Legma, JB. Amélioration des propriétés physico-chimiques et microbiologiques des sols par des fertilisants biologiques sous cultures de la tomate en zone Soudano-sahélienne. *Afrique SCIENCE* 2021; 19(4):189 - 202

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