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NATIVE *TRICHODERMA* SPECIES WITH POTENTIAL IN THE GROWTH OF SEEDLINGS OF MAIZE JALA RACE

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Abstract: The study evaluated the efficacy of several native *Trichoderma* strains on the growth of Jala maize. Soil samples were collected from 15 locations in Nayarit and Oaxaca, where 51 strains were isolated, with *T. viride, T. asperellum* and *T. harzianum* standing out. Of these, *T. viride* showed the best performance in solid and liquid media, with rapid growth and high biomass production, with strain 48 standing out. In germination and root development, *T. asperellum* (strain 69) and *T. harzianum* (strain 42) also showed good results, although they were surpassed by *T. viride*. Soils with pH close to neutral favored the diversity of *Trichoderma*, highlighting the "Tierra Oaxaca" as one of the richest in strains. *Trichoderma* applications significantly improved the germination speed index, root length and diameter of the treated plants, which evidences its potential as a biofertilizer and growth promoter. In conclusion, *T. viride* strains, particularly strain 48, showed better experimental performance in strengthening the yield of Jala maize, while *T. asperellum* and *T. harzianum* offer complementary applications at different stages of the crop.
Keywords: *Trichoderma*, Maize race Jala.

INTRODUCTION

Species of the genus *Trichoderma* are widely studied because of their potential as biological control agents and biostimulants. Traditionally, it is assumed that their effectiveness is most evident during early stages of plant development, such as germination and initial growth, but is limited in advanced stages such as fruit ripening. Among the most outstanding species, *Trichoderma harzianum* T-22 is differentiated by combining mycoparasitism, production of hydrolytic enzymes, antibiosis and induction of systemic resistance in plants, which positions it as a model for study in sustainable agricultural systems (Harman et al., 2004) . On the other hand, other *Trichoderma* species present less complex mechanisms, such as competition for space and nutrients in the rhizosphere, without manifesting direct activities such as the production of antifungal metabolites (Howell, 2003) .

Indirect mechanisms of action of *Trichoderma* sp., such as competition for space and nutrient resources, play a crucial role in the promotion of plant health. These processes are modulated by environmental factors such as pH, nutrient availability, temperature and iron concentration, which condition their effectiveness in biological control (Benítez et al. 2004) . In addition, the production of phytohormones, such as auxins and gibberellins, associated with the use of *Trichoderma*, contributes significantly to plant vigor, which favors root development and growth in height (Contreras et al., 2016) However, the molecular interaction between *Trichoderma* and plants, mediated by volatile organic compounds and other secondary metabolites, is not yet fully understood, as its efficacy seems to depend largely on environmental conditions (Nieto-Jacobo et al., 2017) .

On the other hand, maize of the Jala race stands out for its unique characteristics, such as the length of cobs that reached up to 60 cm and plants of more than 5 meters in height, which makes it one of the most representative races in Mexico (Kempton, 1924) . However, during the last decades a decrease in cob size to 30.5 cm was observed (Wellhausen et al., 1951) . Currently, through genetic improvement the ear size reached a maximum length of 36 cm and a minimum of 21 cm, this decrease in ear size is attributed to the genetic drift of maize Jala race, and agroclimatic factors, and water and nutrient restrictions in the soil this race faces significant challenges to maintain its productivity and relevance. ((Aguilar et al., 2006) .; Mandujano et al. 2018).

TARGET

The purpose of this research was to evaluate the biostimulant potential of native isolates of *Trichoderma sp*. with antagonistic activity, analyzing their effectiveness during the germination process of Jala maize seeds. This study seeks to contribute to the understanding of the role of *Trichoderma* in the promotion of plant growth, as well as in the preservation and improvement of one of the most emblematic maize breeds.

MATERIALS AND METHODS

The study was conducted in March 2024, in 15 locations distributed as follows: in the municipality of Jala, Nayarit, a soil sample was taken from the crops of Jala corn and yellow forage corn, peanuts, Jamaica and soil from the Ceboruco hill ecosystem. In the town of Niza Limón, in the neighborhood of La Soledad, Oaxaca, a soil sample was obtained where Jala breed corn was planted. In Pajaritos, municipality of Tecuala, Nayarit, a soil sample was obtained with forage corn. The soil was selected from the middle part of the plot destined to the crop. The soil surface was carefully cleaned to remove surface organic matter. With a straight shovel, a 15 cm deep hole was dug, and approximately 200 grams of soil were collected. In the same plot, four subsamples were taken following this procedure. The subsamples were placed in high density polyethylene bags with a capacity of 2 kg. The samples were then transferred to the microbiology laboratory of the Instituto Tecnológico de Tepic for storage and processing. The pH of the soil samples collected at the different sites sampled was measured using a Hanna brand potentiometer, model HI98128.

ISOLATION AND STRAIN SELECTION

For the isolation of *Trichoderma* sp., 1 g of soil was weighed and previously sieved through a 50 µm tyler sieve. Samples were placed in screw eppendorf tube with peptonized water and allowed to stand for 24 hours and the 1/10 (w/v) soil dilution method was used. Aliquots of 50 µl of this dilution were taken and dispersed on V-8 juice agar culture medium, 1000 µl of lactic acid was added. Then, three replicates of each sample were incubated in Petri dishes for 10 days at 24 °C. *Trichoderma* sp. colonies were identified morphologically by their rapid growth and characteristic green or white patchy appearance. The *Trichoderma* sp. isolates obtained were purified on potato-dextrose agar (PDA) culture medium, as described by the authors Chaverri and Samuels (2003) .

CHARACTERIZATION OF THE TAXONOMY OF *Trichoderma* sp

For taxonomic studies of the genus *Trichoderma*, the following culture media were used: cornmeal dextrose agar (CMD), composed of 17 g cornmeal and 20 g glucose in 1000 ml distilled water, and synthetic low nutrient medium (SNA), composed of 1.0 g KH_2PO_4, 1.0 g KNO_3, 0.5 g $MgSO_4$-$7H_2O$, 0.5 g KCl, 0.2 g glucose, 0.2 g sucrose and 20.0 g agar in 1000 ml distilled water. A microscope and stereo microscope were used to observe and measure the fungal structure. Colony characteristics such as color, odor, presence of pustules, aerial mycelium and pigmentation of the medium were recorded, as well as the time it took for the fungus to cover the fungal surface. Structures such as conidia, flagella, chlamydospores and conidiophores were also observed. For species level identification, the classification keys of Chaverri and Samuels (2003), Barrera et al. (2021) and Samuels, A., et al. (2010) were used.

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In vitro GROWTH OF *Trichoderma* IN SOLID MEDIUM

The isolated and characterized *Trichoderma* strains were evaluated by solid medium kinetics. Each strain of *Trichoderma* fungus was grown for 5 to 6 days. 5.9% PDA medium was prepared at a 1:1 (v/v) ratio and sterilized in an autoclave at 15 lb/in² and 120 °C for 15 min. Once the PDA mixture solidified at the corners of the Petri dish, a 7 mm diameter *Trichoderma* mycelial disc of *Trichoderma* mycelium was inoculated. The treatment was incubated at 24 ± 1 °C for a period of 6 to 8 days, until the Petri dish was completely covered with mycelium where mycelial growth was measured every 24 hours for 7 days (Salinas Méndez, 2017) .

In vitro GROWTH OF *Trichoderma* IN LIQUID MEDIUM

The kinetics in liquid medium determined the biomass produced by the growth of *Trichoderma sp.* strains for 5 to 6 days. Subsequently, sterilized distilled water was added to the Petri dish, transferred to a screw cap tube and shaken to separate the spores, which were then filtered with sterile gauze. The spore concentration used for inoculation was 1x10^7 sp/ml, measured in a Neubauer chamber. Potato dextrose broth medium was prepared in flasks with the amount of 200 ml, sterilized at 120 °C for 15 minutes. Each inoculated strain was kept in agitation at 150 rpm for 7 days.

A microcentrifuge was used to determine the biomass. The empty PCR tube was preweighed until a constant weight was reached, then 1 ml of the culture was added, performing the process in triplicate. Centrifugation was carried out at 10,000 rpm for 10 minutes. Subsequently, the liquid was removed from each tube and placed in an oven at 80 °C to dry the biomass. Once a constant weight was reached, the tube was weighed again, subtracting the weight of the empty tube to obtain the final weight of the biomass (Valiño et al., 2010) .

APPLICATION OF *Trichoderma* IN THE GERMINATION OF JALA MAIZE SEEDS

Seeds of maize *(Zea mays* L.) Jala race were sown in plastic trays with capacity for 72 seeds. The best *Trichoderma* strains evaluated and selected for their biomass production and rapid growth were used. Each strain was evaluated at three different concentrations: 1x10^4, 1x10^7 and 1x10^10 sp/ml. The concentration of conidia was measured in a Neubauer chamber.

The number of germinated seeds was evaluated daily, considering radicle emission as the germination criterion. From this, days and germination percentages were determined. In addition, the germination velocity index (GVI) was calculated using the formula: $IVG = \sum (ni/ti)$, where: IVG represents the germination speed index, ni is the number of germinated seeds and ti is the time required to reach the highest germination percentage (Carrillo-Sosa et al., 2017) .

Root length and diameter of 20 seedlings were measured for each treatment and, subsequently, each plant was placed in an oven at 80 °C for 4 days to dehydrate it and obtain its dry weight. Analysis of variance and comparison of means of the treatments were performed using Tukey's method ($p > 0.05$).

RESULTS AND DISCUSSION

SOIL PH

The pH values obtained ranged from a minimum of 3.89 to a maximum of 9.86 in the different localities evaluated, with a significant correlation between soil acidity or alkalinity and microbial diversity. In particular, soils with a pH close to neutral (such as Volcán 2 and Volcán 3) presented a greater diversity of fungi of the genus *Trichoderma*, suggesting that an environment with a balanced pH is more favorable for the development of these

NO.	Sample location	Cultivation	pH	NO.	Sample location	Cultivation	pH
1	Land of Volcano 1	Ecosystem	3.89	9	Tierra de Maíz breed Jala 01	Corn	5.92
2	Land of Volcano 2	Ecosystem	7.02	10	Tierra de Maíz breed Jala 02	Corn	6.67
3	Land of Volcano 3	Ecosystem	7.53	11	Tierra de Maíz breed Jala 03	Corn	7.56
4	Land of Volcano 4	Ecosystem	6.94	12	Land of Tecuala	Corn	7.78
5	Forage corn land 01	Corn	7.42	13	Oaxaca Land	Corn	8.85
6	Forage corn land 01	Corn	6.13	14	Land of Jamaica	Jamaica	9.86
7	Peanut soil 01	peanut	5.8	15	Tierra de Cerro	Ecosystem	7.64
8	Peanut land 02	peanut	7.37				

Table 1. Soil pH collected at different locations.

Note: Own elaboration; representative sample of 15 localities of interest for the study.

fungi. On the other hand, the locality "Tierra Oax" that presented an alkaline pH (8.85) showed the highest amount of *Trichoderma* isolates (15 strains), which could be related to its capacity to adapt to diverse edaphic, nutritional and biological conditions (Table 1). This result is consistent with previous studies indicating that *Trichoderma* can thrive in a wide pH range, although individual strains may show preferences for specific soil conditions (Samuels, Ismaiel, et al., 2010) .

ISOLATION AND CHARACTERIZATION OF *Trichoderma* sp

Thirteen isolates of *T. viride,* eight *T. asperellum*, and five *T. harzianum*, known for their ability to promote growth and biological control of plant diseases, were identified by morphology and taxonomy. In addition, 25 isolates were obtained that lacked to be characterized by their morphology, however, they present potential characteristics to promote plant growth. Previous studies have shown that different *Trichoderma* species vary in their efficacy as biostimulants and for the control of pathogens in economically important crops under certain environmental conditions (Harman, 2000; Rodriguez, 2007) . In this sense, the precise identification of the species is decisive to develop more effective applications in the field.

DISTRIBUTION OF *Trichoderma* IN SOIL SAMPLES

Different groups of *Trichoderma* were identified in 15 soil samples collected from different locations and crop types. The results show a heterogeneous distribution of species, which highlights the variability in soil colonization by this fungal genus (Figure 1 and Table 2).

Group 1: *Trichoderma asperellum.* *Trichoderma asperellum* was detected in 4 of the 15 samples with a total of 8 isolated strains, being more abundant in "Maíz Jala 01" (3 records) and "Tierra de Verano" (2 records). *T. asperellum* seems to be associated with agricultural soils, especially those that support crops such as maize and monoculture agricultural systems, due to its adaptive capacity and potential as a biological control agent. According to Hermosa et al. (2012) , *T. asperellum* is widely recognized for its ability to promote plant growth and enhance resistance against pathogens.

Group 2: *Trichoderma viride.* *Trichoderma viride*, was one of the most frequent, with detection of 13 isolates, distributed in "Oaxaca" soil with four isolates, in Jala soil in "Maíz Forrajero 01" with 2 isolates, and "Maíz Forrajero 2" soil with 1 isolate. The Jala ecosystem shows Volcan 2 with one isolate and Volcan 3 with one isolate. Cacahuate 01 in Jala soil with two isolates.

Tecuala soil with one isolate. Its ability to adapt to different edaphoclimatic conditions is reaffirmed, being a potentially useful microorganism for various strategies of sustainable agricultural management is known for its ability to colonize diverse soils thanks to its tolerance to variations in pH and texture (Benítez et al., 2004) .

Group 3: *Trichoderma* *harzianum***.** *Trichoderma harzianum* was identified in 5 localities, with its greater presence in the sample of "Tierra Oaxaca" (3 records). This pattern of distribution could be related to specific factors of the soil, as the content of organic matter or the interactions with other microorganisms, that favor its development. Its capacity as an antagonist of phytopathogenic fungi and plant growth promoter has been widely documented (Harman et al., 2004) .

Group 4: *Trichoderma sp3.* Group 4 presented a null presence in most of the samples, except in Volcán 2 and Volcán 3. Its limited distribution suggests a dependence on specific microenvironmental factors, such as pH or volcanic activity, which coincides with previous studies that highlight the ecological preferences of species of the genus (Kullnig et al., 2001) .

Group 5: *Trichoderma sp1.* With 14 records, this group stood out in "Tierra Oaxaca" (8 records) and in "Maíz Forrajero 01" (4 records). According to Blaszczyk et al. (2014) , colonization by unclassified *Trichoderma* species may depend on soil organic content and symbiotic interactions in agricultural regions.

Group 6: *Trichoderma sp.* This group presented the lowest number of records (4), detected in "Volcán 1" and "Maíz Forrajero 02". Its low frequency could be due to specific environmental requirements for its growth and colonization (Schuster and Schmoll, 2010) . The significant presence of *T. asperellum*, *T. viride* and *T. harzianum* in specific localities highlights their potential as biofertilizing and biological control agents. In particular, the "Tierra Oaxaca" and "Maíz Jala" samples show favorable conditions for their proliferation, which makes them key areas for future research focused on the development of agricultural bioinputs.

The heterogeneous distribution of *Trichoderma* observed reflects the influence of factors such as crop, pH and local edaphic conditions. *T. asperellum* was prominent in maize soils, especially in monocultures, coinciding with studies highlighting its adaptive capacity (Hermosa et al., 2012) . On the other hand, *T. viride* was the most frequent species and was detected in several localities, showing its tolerance to environmental variations (Benítez et al., 2004) . *T. harzianum*, although less frequent, exhibited a high presence in "Tierra Oaxaca", probably due to its adaptation to soils rich in organic matter (Harman et al., 2004) .

Trichoderma GROWTH ON SOLID MEDIUM (PDA)

The analysis of the isolated *Trichoderma* strains highlighted the variability in their ability to stimulate the growth of maize plants. According to the categorized results, Group 2 (*Trichoderma viride*) showed an outstanding performance compared to the other groups. Within this, Strain 73 stood out in growth measurements at 72 hours, while Strain 48 led development at 144 hours, reaching an average of 74.77% coverage on solid media. This performance coincides with previous studies that have demonstrated the effectiveness of T. viride as a biostimulant and biological control agent (Harman, 2000; Salinas Méndez, 2017) .

Group 1 (*Trichoderma* asperellum) presented a consistent performance, with Strain 69 showing superior results in the initial measu-

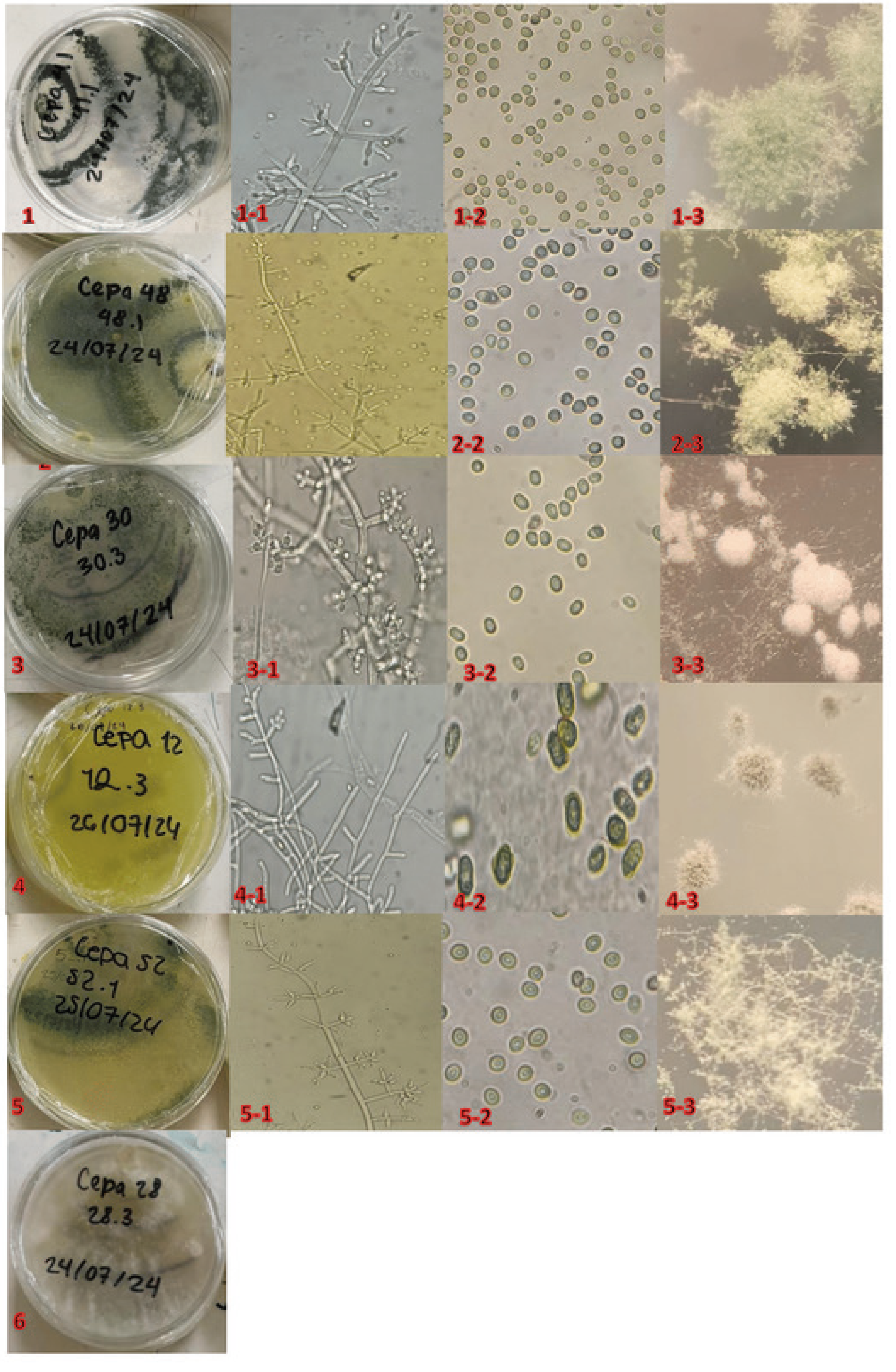
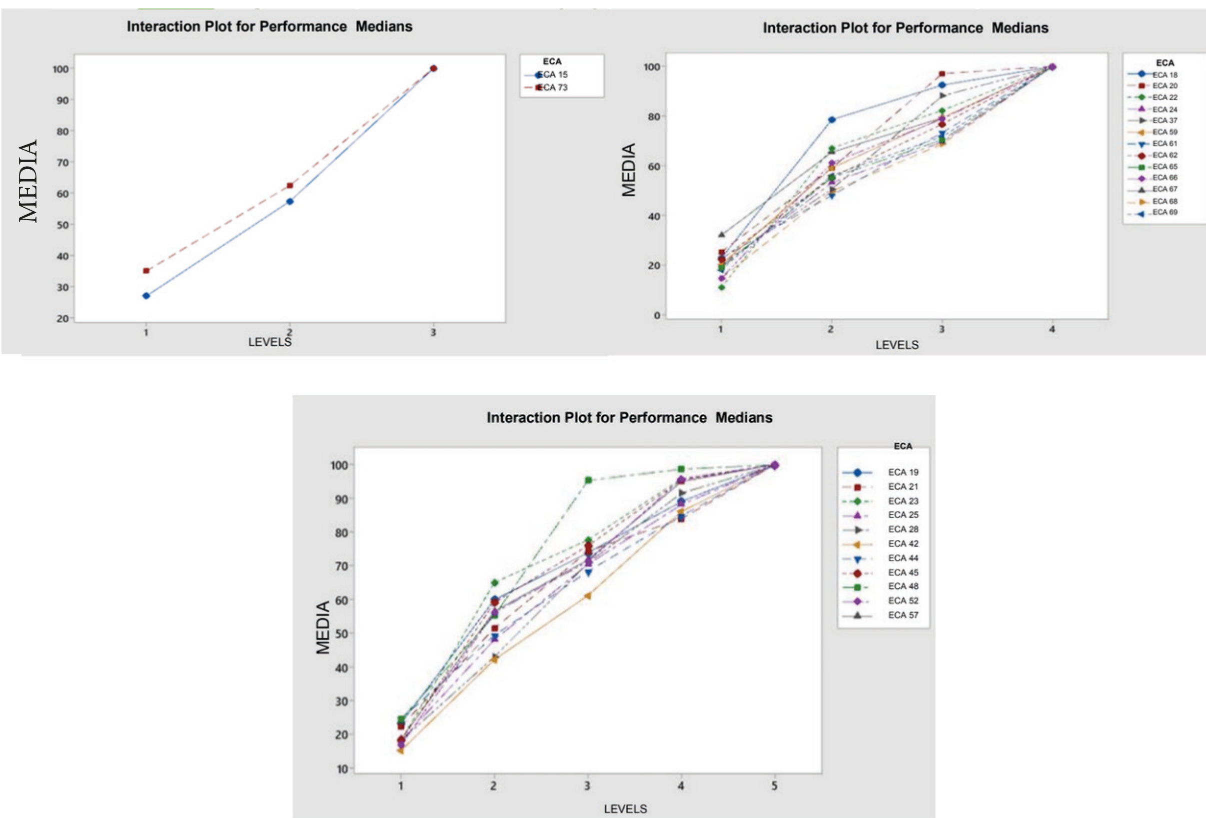


Figure1. 1 strain *Trichoderma asperellum*, 1-1 phialides, 1-2 spores, 1-3 pustules. 2 strain *Trichoderma viride* 2-1 phialides, 2-2 spores, 2-3 pustules. 3 strain *Trichoderma harziuanum* 3-1 phialides, 3-2 spores, 3-3 pustules. 4 strain *Trichoderma sp3* 4-1 phialides, 4-2 spores, 4-3 pustule. 5 strain *Trichoderma sp1* 5-1 phialides, 5-2 spores, 5-3 pustule. 6 strain *Trichoderma*

NO.	Sample location	Group 1. *Trichoderma asperellum*	Group 2. *Trichoderma viride*	Group 3. *Trichoderma harzianum*	Group 4. *Trichoderma* sp	Group 5. *Trichoderma* sp	Group 6. *Trichoderma* sp	Total, of isolated
1	Land of Volcano 1						1	1
2	Land of Volcano 2	1	1		5		2	9
3	Land of Volcano 3		1			1		2
4	Land of Volcano 4							0
5	Forage corn land 01		2			4		6
6	Forage corn land 01		1	1			1	3
7	Peanut soil 01		2	1				3
8	Peanut land 02							0
9	Tierra de Maíz breed Jala 01	3		1				4
10	Tierra de Maíz breed Jala 02					1		1
11	Tierra de Maíz breed Jala 03							0
12	Land of Tecuala	2	1					3
13	Oaxaca Land		4	3		8		15
14	Land of Jamaica					0		0
15	Tierra de Cerro	2	1	1				4

Table 2. Distribution of *Trichoderma* in the soil samples.

Note: Own elaboration.



Interaction plots of growth performance by type of ECA and level of elapsed hours.

Note: Own elaboration; hours elapsed to complete 100% growth; a) Strains that completed growth up to 72 h elapsed; b) Strains that completed growth up to 96 h elapsed; c) Strains that completed growth up to 144 h elapsed

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rement times (96 hours). This reinforces the potential of T. asperellum in early applications as a biofertilizer (Barrera et al., 2021) .

On the other hand, Group 3 strains (*Trichoderma harzianum*) had a more moderate performance compared to T. viride and T. asperellum. However, Strain 42 showed a remarkable development in the final interval (144 hours), which makes it relevant for specific applications in advanced stages of cultivation (Benítez et al., 2004) .

Finally, Groups 4, 5 and 6 (*Trichoderma* sp.) included strains with variable potential, with Strain 18 of Group 4 being the most prominent in the first measurements. This suggests that these uncharacterized strains may have specific applications depending on crop conditions and timing of application (Chaverri and Samuels, 2003) .

AVERAGE GROWTH OF *Trichoderma* IN LIQUID POTATO DEXTROSE MEDIUM

The analysis of *Trichoderma* strains allowed the identification of significant differences between categories in terms of growth performance and biostimulant potential. The data obtained in liquid media highlight the capacity of some species to produce biomass in an efficient and uniform way, being a key factor for their agricultural applicability.

In Group 1 (*Trichoderma asperellum*), Strain 69 stood out for its performance in the early stages of the experiment, showing a high growth rate and adaptation in liquid media. This behavior is consistent with studies highlighting the ability of T. asperellum to compete for space and nutrients in the rhizosphere (Hermosa et al., 2012).

Group 2 (*Trichoderma viride*) showed an outstanding performance, especially with Strain 48, which achieved the best results in production of biomass and growth rate at 144 hours. This result reinforces its position as one of the most effective species in plant growth promotion and biological control (Benítez et al., 2004) .

In Group 3 (*Trichoderma harzianum*), Strain 42 presented a remarkable development, standing out for its consistency in biomass production. This group is recognized for its ability to generate secondary metabolites with antifungal effects (Harman et al., 2004) .

Groups 4, 5 and 6 (*Trichoderma* sp.) showed variable performance, with Strain 18 of Group 4 being the most promising. Although these strains are not fully characterized, the results suggest significant potential for specific applications in agricultural management (Schuster and Schmoll, 2010) .

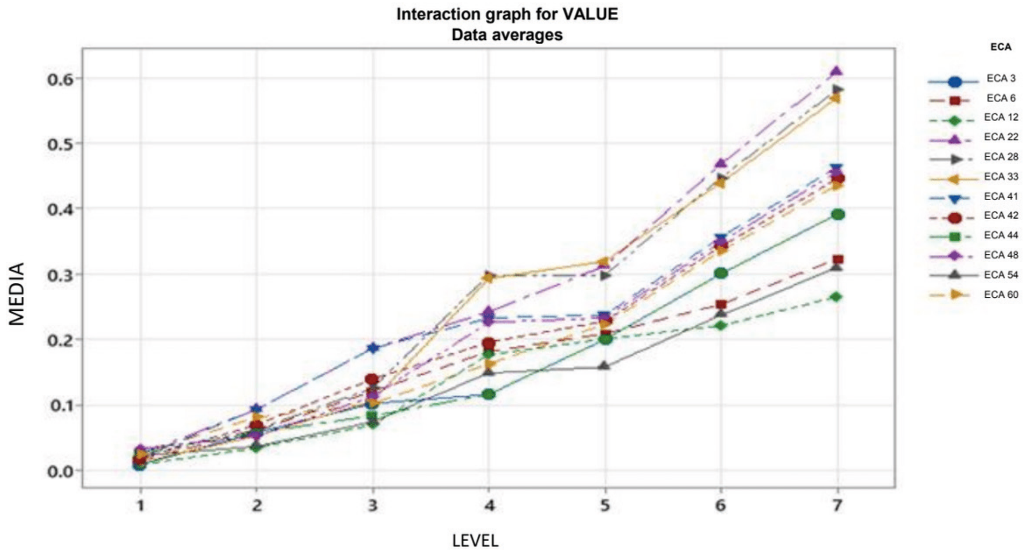
In general, *T. viride* and *T. asperellum* emerge as the most outstanding species, not only for their rapid growth, but also for their ability to improve soil conditions and promote plant health. These characteristics position them as key tools in sustainable agricultural strategies.

Grouping information using the Tukey method and a confidence level of 95%.			
ECA	N	MEDIA	Grouping
22	21	0.2771	A
28	21	0.262867	A B
33	21	0.256667	A B C
41	21	0.227633	A B C D
48	21	0.209524	B C D E
42	21	0.206033	C D E
60	21	0.195667	D E
44	21	0.168667	E F
3	21	0.168667	E F
6	21	0.1668	E F
54	21	0.141667	F
12	21	0.140106	F

Table 3. Measurement of *Trichoderma* growth performance.

Note: Own elaboration; measurements that do not share a letter are significantly different.

The test run was based on Tukey's method for 95% confidence.



Interaction plots of growth performance by type of ECA and level of elapsed hours.

Note: Own elaboration; average growth from 24 h to 192 h.

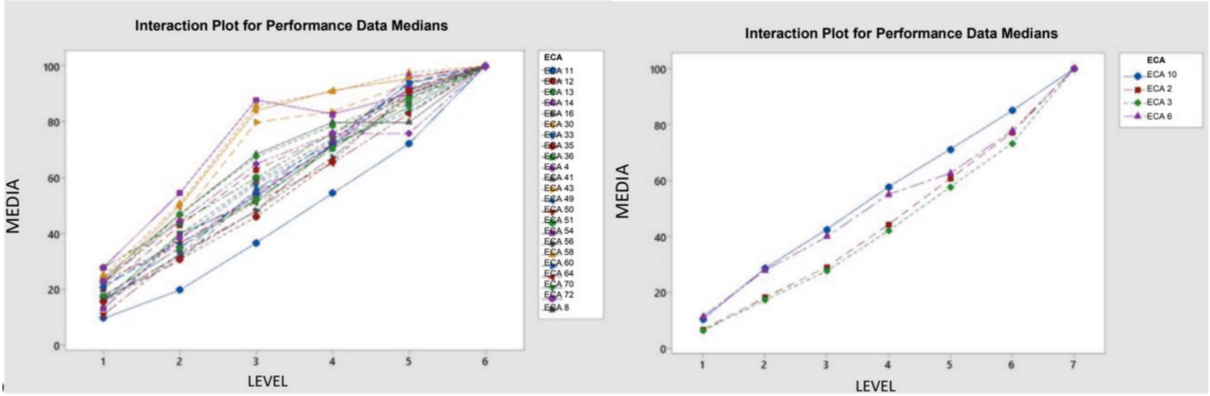


Figure 4. Interaction plots of Growth performance by ECA type and level of elapsed hours.

Note: Own elaboration; hours elapsed to complete 100% growth; a) strains that completed growth up to 168 h elapsed; b) strains that completed growth up to 192 h elapsed.

Grouping information using Tukey's method and a confidence level of 95%.											
Plant height			Root length			Plant Diameter			diameter		
ECA 22	6.163	A	ECA 41	13.05	A	ECA 41	2.715	A	ECA 41	2.326	A
ECA 42	6.06	A B	ECA 22	12.27	A B	ECA 6	2.697	A	ECA 22	2.066	B
ECA 41	5.755	B C	ECA 42	10.86	B C	ECA 22	2.601	A B	ECA 42	2.005	B C
ECA 48	5.413	C	ECA 6	9.873	CD	ECA 48	2.45	B C	ECA 48	1.828	CD
ECA 6	4.69	D	ECA 48	9.843	CD	ECA 42	2.27	C	ECA 6	1.648	D
CONTROL	4.495	D	CONTROL	8.49	D	CONTROL	1.94	D	CONTROL	1.225	E

Table 4. 7-day plant growth results

Note: Own elaboration; measurements that do not share a letter are significantly different. The test run was based on Tukey's method for 95% confidence.

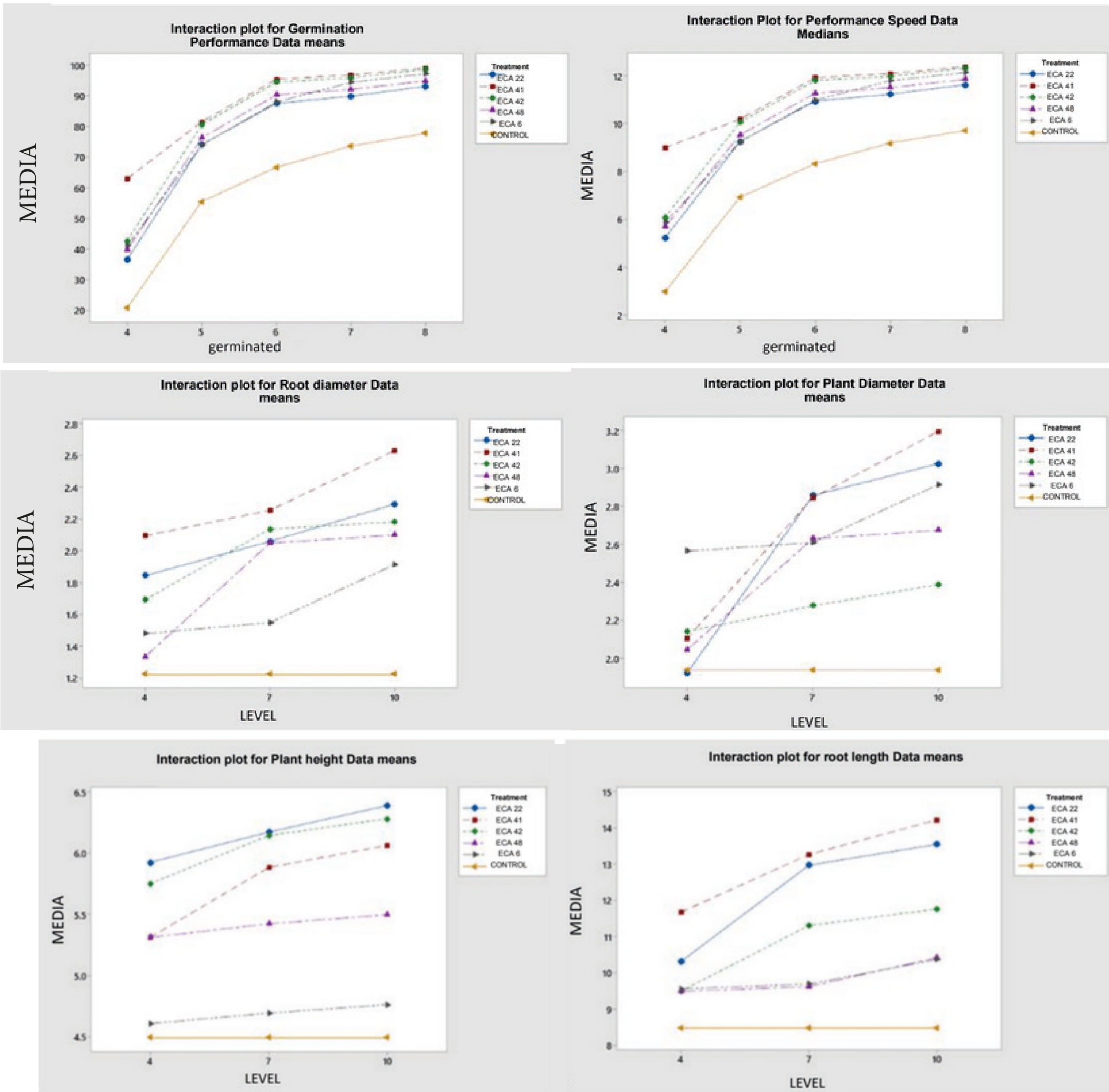


Figure 5. Interaction plots of the performance of the study variables.

Note: Own elaboration; the study variables were: performance of (a) proportion of germinated seeds, (b) plant growth rate, (c) root diameter measurement (mm), (d) plant diameter measurement (mm), (e) plant height (cm) and (f) root length (cm).

EFFECT OF *Trichoderma* ON JALA MAIZE SEED GERMINATION

In the present analysis, different *Trichoderma* species and strains were evaluated under various performance parameters in agricultural crops, including seed germination, plant growth rate, plant height, root length, plant diameter and root diameter. This analysis provides critical information on the best performing species and strains, allowing future agricultural and biotechnological applications to be guided.

SEED GERMINATION

Seed germination is a key indicator of the efficacy of a biocontroller such as *Trichoderma*. In this study, *Trichoderma asperellum* strains (Group 1) showed the best results in terms of proportion of seeds germinated in the first seven days. This is in agreement with previous studies highlighting *T. asperellum* as an effective germination promoter due to its ability to produce indoleacetic acid (Singh et al., 2020) .

PLANT GROWTH RATE

In the growth rate category, *Trichoderma viride* strains (Group 2) outperformed other species evaluated. The ability of this species to release hydrolytic enzymes and solubilize nutrients may explain its superior performance (Harman et al., 2004) . Specifically, strains 16 and 20 showed significantly faster growth compared to others, suggesting their potential for applications in short-cycle crops.

PLANT HEIGHT

The height of plants treated with *Trichoderma harzianum* (Group 3) stood out significantly, especially strains 72 and 57. These results are consistent with research indicating that *T. harzianum* can promote plant growth by enhancing nutrient uptake and stimulating phytohormone production (Contreras-Cornejo et al., 2016) .

ROOT LENGTH

For root length, Group 4 strains (*Trichoderma sp.*) such as strain 6 showed the highest values. Root extension is critical for water and nutrient uptake, and Group 4 strains showed remarkable superiority. This could be attributed to the production of volatile compounds that promote root elongation (Vinale et al., 2008) .

PLANT DIAMETER

The diameter of the plant is a parameter related to the robustness and general health of the crop. Group 5 strains (*Trichoderma sp.*), in particular strain 22, presented a greater diameter in the treatments. This confirms the potential of these strains to improve plant vigor (Mastouri et al., 2010).

ROOT DIAMETER

Finally, root diameter was larger in plants treated with Group 6 (*Trichoderma sp.*) strains, such as strain 2. Larger root diameter may be related to better tolerance to water or nutritional stress conditions, a key feature in its agricultural application (Woo et al., 2014) .

CONCLUSION

The study highlighted the ability of various *Trichoderma* strains to improve the germination and development of Jala maize seedlings. Among them, *Trichoderma viride*, especially strain 48, was identified as the most efficient due to its outstanding contribution in biomass production performance measures of growth rate and its remarkable ability to stimulate root development as well as seed germination. Its adaptability to different soil conditions and its consistent performance in solid and liquid media position it as a key biotechnological tool for sustainable agriculture. In addition, strains of *T. asperellum* (strain 69) and *T. harzianum* (strain 42) showed favorable results, excelling in specific crop stages. These species not only reinforce the potential of *Trichoderma* as a biofertilizer and biological control agent, but also offer versatile alternatives to optimize the yield of Jala maize under diverse conditions.

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