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Effects of *Trichoderma harzianum*, effective microorganisms, and plant density on the yield of *Sesamum indicum* L. under tropical humid conditions: A field study in Pichari, Peru

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Abstract
This study evaluated the effect of planting density, *Trichoderma harzianum*, and Effective Microorganisms (EM) on the agronomic performance of *Sesamum indicum L.* under humid tropical conditions in Pichari, Peru, during the 2024 agricultural season. A randomized complete block design with a 2 × 2 × 2 factorial arrangement was used, including two planting densities (119,000 and 143,000 plants ha^{-1}), with or without application of T. *harzianum* and EM. Growth variables and yield components, including plant height, capsule number, and grain yield, were evaluated. Significant effects were observed for the interaction between T. *harzianum* and EM on grain yield (p = 0.0424). The highest yield (1,252 kg ha^{-1}) was obtained with the treatment combining T. *harzianum* and 143,000 plants ha^{-1}. In addition, treatments inoculated with T. *harzianum* showed higher numbers of capsules per plant compared with non-inoculated treatments. The results indicate that microbial inoculation, particularly with T. *harzianum,* may contribute to improving sesame productivity under tropical field conditions in the Peruvian Amazon.

Keywords*: Trichoderma harzianum, effective microorganisms, plant density, bioinputs, agronomic yield, Sesamum indicum L.*

Introduction

Global sesame production reached approximately 6.6 million tons in 2023, mainly concentrated in Asia and Africa due to increasing demand from the food, pharmaceutical, and cosmetic industries (FAO, 2023). Sudan and India remain among the principal producers and exporters (UNCTAD, 2018), while nearly 58% of international exports are directed toward markets such as China and Japan (IDB, 2021). Despite its commercial value and high antioxidant oil content (UNCTAD, 2024), sesame productivity continues to be affected by insect pests and phytopathogens, including *Smicronyx* spp., *Spodoptera frugiperda*, *Fusarium* spp., and *Cercospora* spp., which reduce yield and seed quality during storage. In Latin America, Paraguay, Mexico, and Brazil are among the main sesame-producing countries, with Paraguay reporting approximately 49,500 tons annually (IDB, 2021). However, production expansion in the region remains limited by the use of low-yielding local genotypes, reduced mechanization, and persistent phytosanitary problems associated with pests such as *Helicoverpa* armigera and *Frankliniella schultzei* (Colorado-Pérez et al., 2023; Pérez et al., 2024). In Peru, sesame production reached 5,210 tons in 2023, mainly in the regions of Piura and Lambayeque, with approximately 2,600 tons exported to Asian markets (MIDAGRI, 2025). Nevertheless, production is still constrained by inadequate irrigation practices, limited availability of improved varieties, and the incidence of pests and diseases such as *Aphis gossypii* and *Rhizoctonia solani* (Acosta-Román et al., 2023). Phytosanitary limitations represent one of the main constraints for sesame cultivation worldwide. According to Dwarka et al. (2024)

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infestations caused by *Antigastra catalaunalis* and aphids may reduce yield by up to 70% under severe conditions. Similarly, Kefale et al. (2021) reported high prevalence of insect pests and disease severity in sesame-producing areas of Ethiopia, particularly for Cercospora leaf spot and bacterial blight. Under these conditions, integrated pest management has become an important strategy for improving crop sustainability. Biological control methods based on parasitoids such as *Trichogramma chilonis*, nucleopolyhedroviruses, and entomopathogenic fungi including *Metarhizium anisopliae* have shown favorable results in reducing populations of *H. armigera* (Mishra et al., 2021). In addition, intercropping systems with millet or castor have contributed to lowering Antigastra incidence while promoting natural enemy populations and improving yield performance (Sheeba Jasmine et al., 2020). Other studies have demonstrated that combining neem-based products, pheromone traps, and parasitoids can maintain pest incidence below economic threshold levels in sesame fields (Alemu and Taye, 2022). Likewise, postharvest management using hermetic storage systems such as PICS and SGP bags has improved seed conservation compared with conventional storage methods (Berhe et al., 2023). Population dynamics studies have also contributed to establishing Economic Threshold Levels for more efficient pest management decisions (Ram et al., 2025; El-Shannaf et al., 2024; Roy, 2022), whereas timely weed control has been associated with lower disease incidence in the crop (Gedifew and Earecho, 2024). Among the biological alternatives currently used in sustainable agriculture, *Trichoderma spp.* has received considerable attention because of its role in mycoparasitism, antibiosis, and induction of plant defense responses (Oyesola et al., 2024; Poveda, 2021; Monte, 2023). Previous studies have shown that *Trichoderma* can reduce soil-borne diseases, improve nutrient uptake, and promote yield increases under different agricultural conditions (Guzmán-Guzmán et al., 2023; Yao et al., 2023; Harman, 2024). In addition, reductions in foliar pathogen incidence between 40% and 70% have been reported after its application (Tyśkiewicz et al., 2022). Positive interactions with arbuscular mycorrhizae and crop rotation systems have also been documented, contributing to improvements in crop performance and arthropod diversity (Yağmur et al., 2024; Awal et al., 2024; Caccavo et al., 2022). Considering these factors, sustainable sesame production requires integrated management strategies that combine biological control, cultural practices, and agronomic optimization. In this context, the use of beneficial microorganisms such as *Trichoderma spp.* represents a promising alternative for improving crop productivity and reducing phytosanitary limitations under tropical production conditions. *Sesame (Sesamum indicum L.)* is a burgeoning oilseed in Peru, prized for its 45–58% oil content and nutritional value. Its oil quality surpasses that of soybean or sunflower due to its high concentration of unsaturated fatty acids and antioxidants (Bustamante et al., 2001). Nationally, Piura, Lambayeque, Ica, and La Libertad concentrate 94% of production (Acosta-Román et al., 2023), with new expansion into Amazonian areas like Pichari (MIDAGRI, 2025). These regions offer ideal conditions: well-drained alluvial soils and optimal temperatures between 25°C and 35°C. Planting is primarily manual, utilizing furrows spaced 60–70 cm between rows and 10–15 cm between plants. Optimal densities range from 110,000 to 150,000 plants/ha (Montoya et al., 2019; Melgarejo et al., 2020). Notably, a density of 143,000 plants/ha, when combined with biological treatments, significantly enhances yield efficiency (Montoya et al., 2019). Promising Peruvian varieties include Aceitera Mejorada and Criolla de Reque, selected at the Vista Florida Experimental Station – Chiclayo, with yields of 898 and 767 kg/ha and cycles of 102–110 days (MIDAGRI, 2025). The "Campo Verde" line was also developed through individual selection, adapted to ultisol soils with yields up to 0.8 t/ha. Management involves manual weeding, thinning, and harvesting. Fertilization relies on soil analysis, often supplemented with biostimulants like vermicompost and effective microorganisms (Héctor-Ardisana et al., 2021). Preventive strategies include using Trichoderma spp., which enhances growth and suppresses pathogens like *Fusarium* through root colonization (Oyesola et al., 2024; Ruiz & Blandón, 2021). Specifically, trials in Pichari demonstrated that *Trichoderma harzianum* significantly increased plant height, capsule count, and grain yield (Galindo et al., 2024). Key pests in Peru include *S. frugiperda*, *A. gossypii*, *F. schultzei*, and *E. kuehniella* (Colorado-Pérez et al., 2023; Dwarka et al., 2024). Major diseases include anthracnose, *Cercospora sesami*, and *Rhizoctonia solani* (Melgarejo et al., 2020). Integrated Pest Management (IPM), merging biological, cultural, and chemical controls, remains the most effective strategy (Mishra et al., 2021). Harvesting begins when 70–80% of capsules mature. To prevent infestations by *Tribolium spp.* and *C. cephalonica*, seeds must be stored at less than 9% moisture (Berhe et al., 2023). Hermetic bags (PICS) are recommended to minimize postharvest losses. Based

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on these factors, the primary objective is to evaluate the effect of plant densities, *Trichoderma harzianum*, and effective microorganisms on sesame yield in Pichari Baja (577 m asl), Cusco, 2024. Therefore, this study evaluated the effect of planting density, *Trichoderma harzianum,* and Effective Microorganisms on sesame productivity under humid tropical conditions in Pichari, Cusco. Hypothesis: The synergistic application of *Trichoderma harzianum* and effective microorganisms (EM), especially at higher planting densities, significantly improves sesame (*Sesamum indicum L.*) agronomic performance—specifically plant height, capsule count, and grain yield—compared to individual or non-biological treatments in humid tropical environments.

Materials and methods

The experiment was conducted during the 2024 agricultural season at the Pichari Baja Experimental Center, located in the district of Pichari, La Convención province, Cusco region, Peru, at 577 m a.s.l. (12°13'00" S; 73°49'30" W). The study area is characterized by a warm and humid tropical climate, with an average annual temperature of 24 °C and mean annual precipitation of approximately 1,100 mm, mainly concentrated between November and April. The soil presented a sandy-loam texture, good drainage conditions, and a pH ranging from 6.3 to 6.8, which is considered suitable for the cultivation of Sesame. A randomized complete block design (RCBD) with a 2×2×2 factorial arrangement was used. The evaluated factors consisted of two planting densities (119,000 and 143,000 plants ha^{-1}), application or non-application of *Trichoderma harzianum*, and application or non-application of Effective Microorganisms (EM), resulting in eight treatments. Three replications were established , generating a total of 24 experimental units. Each experimental plot covered 14 m² and consisted of four rows of 4 m length, with 0.70 m spacing between rows. Ten plants were randomly selected from the central rows of each plot, resulting in a total sample of 240 evaluated plants. Sowing was carried out manually using locally selected seeds previously disinfected before planting. *Trichoderma harzianum* was applied at 15 days after emergence (DAE) as a liquid suspension with a concentration of 1×10^7 CFU mL^{-1}. Effective Microorganisms were applied as foliar sprays at 10% concentration at 20 and 40 DAE. Both biological inputs were produced under controlled conditions according to the methodology described by Héctor-Ardisana et al. (2021), and microbial viability was verified prior to application. During the 110-day crop cycle, crop management practices included manual weed control, thinning, pest management using natural extracts, and gravity irrigation based on soil moisture conditions. The evaluated variables included growth parameters, such as reproductive height and plant height, as well as yield-related variables including capsule length, number of capsules per plant, and grain yield (kg ha^{-1}). Plant height was measured from the stem base to the terminal capsule, whereas reproductive height was measured from the root collar to the productive raceme. Harvesting was performed manually, and grain yield from each experimental unit was recorded using a precision digital scale and subsequently extrapolated to kilograms per hectare. Statistical analyses were performed using RStudio version 4.3.1. Analysis of variance (ANOVA) was used to identify significant differences among treatments, and Tukey's honestly significant difference (HSD) test was applied for mean comparisons at $p < 0.05$. Assumptions of residual normality and homogeneity of variances were evaluated using the Shapiro–Wilk and Levene tests, respectively. Results are presented as treatment means and coefficients of variation (Table 1).

Figure 1
Map of study area

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Table 1
Treatments evaluated in a 2×2×2 factorial arrangement under a randomized complete block design (RCBD).

Treatment	Planting Density (plants/ha)	*Trichoderma harzianum.*	Effective Microorganisms (EM)
T1	119,000	Without application	Without application
T2	119,000	With application	Without application
T3	119,000	Without application	With application
T4	119,000	With application	With application
T5	143,000	Without application	Without application
T6	143,000	With application	Without application
T7	143,000	Without application	With application
T8	143,000	With application	With application

Note. Each treatment was replicated three times, with 10 plants evaluated per experimental unit.

Results

Growth traits

Growth-related variables included reproductive height and plant height in *Sesame* cultivated under humid tropical conditions. Reproductive height was determined from the stem base to the first productive node bearing capsules, whereas plant height was measured from the stem base to the terminal capsule at physiological maturity. Measurements were obtained from ten plants randomly selected from the central rows of each experimental unit to minimize border effects. No significant differences were detected for reproductive height among treatments, planting density levels, microbial inoculation, or their interactions ($p > 0.05$). The coefficient of variation (8.03%) indicated acceptable experimental precision under field conditions. Mean reproductive height across treatments was 143.83 cm (Table 2). For plant height, significant differences were observed for the block effect ($p = 0.0056$) and for the interaction between T. harzianum and Effective Microorganisms ($p = 0.0147$). In contrast, planting density, individual microbial applications,

Table 2
Analysis of variance for the growth variables of sesame (Sesamum indicum L.) with Trichoderma and EM, Pichari, 577 m a.s.l., Cusco.

F.V.	gl	Reproductive Height		Plant Height	
		CM	p-value	CM	p-value
Block	2	20.79	0.8392	945.38	0.0056
Treatment	7	118.57	0.4634	191.04	0.2282
Density (D)	1	1.50	0.9115	287.04	0.1487
T. harzianum (T)	1	37.50	0.5805	57.04	0.5068
Effective Microorganisms (M)	1	42.67	0.5558	22.04	0.6784
D x T	1	2.67	0.8822	1.04	0.9280
D x M	1	468.17	0.0654	15.04	0.7317
T x M	1	253.50	0.1634	950.04	0.0147
D x T x M	1	24.00	0.6577	5.04	0.8424
Error	14	117.13		122.90	
Total	23				
CV (%)		8.03		5.33	
Average		143.83		207.88	

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and the remaining interactions did not show significant effects ($p > 0.05$). The coefficient of variation was 5.33%, indicating low experimental variability. Average plant height reached 207.88 cm across evaluated treatments (Table 3).

Table 3
Tukey's test for the effect of planting density, T. harzianum, and Effective Microorganisms (EM) on growth variables of Sesame cultivated under humid tropical conditions in Pichari, Cusco..

F. V.	Factors			Reproductive Height	
	D	Th	EM	cm	
Interaction D x Th x EM	119000	0	1	144.67	a
	143000	1	0	141.00	a
	119000	1	1	137.00	a
	143000	0	1	136.67	a
	143000	0	0	134.33	a
	119000	1	0	130.00	a
	119000	0	0	128.67	a
	143000	1	1	126.33	a
				Plant Height (cm)	
Interaction Th x EM		0	1	226.67	a
		1	0	211.67	a
		0	0	202.17	a
		1	1	201.00	a
				Plant Height (cm)	
Interaction D x Th x EM	143000	0	1	218.67	a
	143000	1	0	215.67	a
	119000	0	1	214.67	a
	119000	1	0	207.67	a
	143000	0	0	206.67	a
	143000	1	1	204.33	a
	119000	1	1	197.67	a
	119000	0	0	197.67	a

Reproductive height ranged from 126.33 to 144.67 cm among treatments. The highest value was observed under the treatment combining EM with 119,000 plants ha^{-1}, whereas the lowest value was recorded under the combination of T. harzianum and EM at 143,000 plants ha^{-1}. However, no statistically significant differences were detected among treatments according to Tukey's test ($p > 0.05$). Similar findings were reported by Montoya et al. (2019), who observed no significant effects of biological fertilization on vegetative growth variables in sesame cultivation. For plant height, mean values ranged from 201.00 to 226.67 cm in the interaction between T. harzianum and EM. Although treatments inoculated with EM showed higher numerical values, all treatments were classified within the same statistical group according to Tukey's test. Likewise, in the interaction between planting density, T. harzianum, and EM, the highest plant height (218.67 cm) was obtained under the treatment with 143,000 plants ha^{-1} and EM, while the lowest value (197.67 cm) was observed in the non-inoculated treatment at 119,000 plants ha^{-1}. The plant height values obtained in the present study were lower than those reported by Melgarejo et al. (2020), who recorded average heights above 260 cm under field conditions. Similarly, Zarate et al. (2011) reported average plant heights close to 229 cm without significant differences among planting densities. According to Beltrão et al. (2001), sesame varieties with indeterminate growth habit may exceed 300 cm in height depending on genotype and environmental conditions.

Yield traits

Yield-related variables included capsule length, number of capsules per plant, and grain yield in Sesame. Capsule length was determined from the base to the apex of mature capsules. The number of capsules per plant was quantified using ten plants randomly selected from the central rows of each experimental unit to reduce border effects. Grain yield was recorded after harvest and expressed as kg ha^{-1} following extrapolation from the harvested area of each experimental plot. No significant differences were detected for capsule length among treatments, planting densities,

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Table 4 *Analysis of variance for the yield variables of sesame (Sesamum indicum L.) with Trichoderma and EM, Pichari, 577 m a.s.l., Cusco.*

F.V	gl	Capsule Length		Capsules per Plant		Grain Yield	
		CM	p-value	CM	p-value	CM	p-value
Block		0.0017	0.8956	1584.91	0.0979	5674.01	0.6657
Treatment	7	0.02	0.3915	1169.60	0.1223	28591.18	0.1109
Density (D)	1	0.0267	0.2037	608.03	0.3212	8085.01	0.4526
T. harzianum (T)	1	0.0417	0.1178	4532.00	0.0140	93887.55	0.0197
Effective Microorganisms (M)	1	0.0067	0.5158	169.60	0.5956	21247.45	0.2309
D × T	1	0.0150	0.3343	74.91	0.7235	55.51	0.9499
D × M	1	0.0000	>0.9999	1187.23	0.1727	1658.34	0.7316
T × M	1	0.0150	0.3343	1597.40	0.1178	67553.87	0.0424
D × T × M	1	0.0150	0.3343	18.03	0.8620	7650.51	0.4648
Error	14	0.0150		574.94		13544.36	
Total	23						
CV (%)		4.18		31.58		10.36	
Average		2.93		75.93		1123.15	

microbial inoculation, or their interactions ($p > 0.05$). The coefficient of variation was 4.18%, indicating low experimental variability under field conditions. Mean capsule length across treatments was 2.93 cm (Table 4). For the number of capsules per plant, significant differences were observed only for the application of T. harzianum ($p = 0.0140$). In contrast, planting density, Effective Microorganisms, and the evaluated interactions did not produce significant effects ($p > 0.05$). The average number of capsules per plant was 75.93. Although the coefficient of variation reached 31.58%, this variability may be associated with the heterogeneous plant response commonly observed under humid tropical field conditions (Table 4). Grain yield showed significant effects for T. harzianum application ($p = 0.0197$) and for the interaction between T. harzianum and Effective Microorganisms ($p = 0.0424$). The remaining factors and interactions did not show significant differences ($p > 0.05$). Mean grain yield across treatments reached 1,123.15 kg ha^{-1}, with a coefficient of variation of 10.36%, indicating acceptable experimental precision (Table 4). As shown in Table 5, capsule length ranged from 2.83 to 3.07 cm among treatments. The highest value was recorded in the treatment combining Trichoderma harzianum with 143,000 plants ha^{-1}, whereas the lowest value was observed in the non-inoculated treatment at the same planting density. However, no statistically significant differences were detected among treatments according to Tukey's test ($p > 0.05$). These values are consistent with the range reported by Montoya et al. (2019) for sesame cultivated under biological fertilization management. The number of capsules per plant varied from 48.47 to 98.87 among treatments. The highest values were obtained in treatments inoculated with T. harzianum and Effective Microorganisms under higher planting density, whereas the lowest values were observed in non-inoculated treatments. Although variability among treatments was observed, the results suggest a favorable response associated with microbial inoculation under tropical field conditions. Overall, treatments inoculated with T. harzianum, either alone or combined with Effective Microorganisms, showed higher values for yield-related variables compared with non-inoculated treatments. These responses may be associated with improved nutrient availability, enhanced root activity, and greater adaptation to environmental stress under humid tropical conditions. Nevertheless, the variability observed among treatments indicates that factors such as microbial compatibility, environmental conditions, and application management may influence the agronomic response of biological inoculants. Further studies evaluating soil properties, native microbiota, and different inoculation strategies are required to improve the understanding of microbial interactions in sesame production systems.

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Table 5
Tukey's test for the effect of planting density, and inoculation with T. harzianum and EM on the yield variables of sesame (Sesamum indicum L.), Pichari, 577 m a.s.l., Cusco.

F. V.	Factors			Capsule lenght		
	D	Th	EM	cm		
Interaction D x Th x EM	143000	1	0	3.07	a	
	143000	1	1	3.00	a	
	143000	0	1	2.97	a	
	119000	1	1	2.93	a	
	119000	0	1	2.90	a	
	119000	1	0	2.90	a	
	119000	0	0	2.87	a	
	143000	0	0	2.83	a	
				Number of capsules per plant		
Trichoderma harzianum Th		1		89.67	a	
		0		62.18		b
				Grain Yield (kg/ha)		
Interaction D x Th x EM	143000	1	1	98.87	a	
	119000	1	0	96.27	a	
	143000	1	0	94.07	a	
	143000	0	1	82.43	a	
	119000	1	1	69.47	a	
	119000	0	1	63.57	a	
	119000	0	0	54.27	a	
	143000	0	0	48.47	a	
				Grain Yield (kg/ha)		
Trichoderma harzianum Th		1		1185.70	a	
		0		1060.61		b
				Grain Yield (kg/ha)		
Interaction Th x EM		1	0	1209.00	a	
		1	1	1162.40	a	b
		0	1	1143.42	a	b
		0	0	977.80		b
				Grain Yield kg/ha		
Interaction D x Th x EM	143000	1	0	1252.00	a	
	119000	0	1	1172.83	a	
	143000	1	1	1171.73	a	
	143000	1	0	1166.00	a	
	119000	1	1	1153.07	a	
	119000	0	1	1114.00	a	
	119000	0	0	988.13	a	
	143000	0	0	967.47	a	

Discussion

The response of the evaluated variables differed according to the agronomic trait analyzed under the application of *Trichoderma harzianum* and Effective Microorganisms (EM). Reproductive height did not show significant differences among treatments, planting densities, or their interactions, indicating that this variable may be more closely associated with the genetic characteristics of the local sesame variety and its adaptation to humid tropical conditions than with microbial inoculation. Similar results were reported by Melgarejo et al. (2020), who observed limited variation in vegetative growth variables under different agronomic management conditions. Although treatments inoculated with EM at lower planting density showed slightly higher numerical values, the absence of statistical significance suggests that the effect of microbial consortia on vegetative growth may depend on environmental conditions, microbial compatibility, and nutrient availability in the rhizosphere. Plant height showed significant differences only in the interaction between *T. harzianum* and EM, which suggests a positive effect associated with combined microbial inoculation. Previous studies have indicated that *Trichoderma*

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ssp. can promote plant growth through improved nutrient solubilization, phytohormone production, and stimulation of root development (Guzmán-Guzmán et al., 2023). Likewise, Harman (2024) reported that *Trichoderma* enhances plant vigor through rhizospheric colonization and activation of plant defense mechanisms. In the present study, the highest plant height values were recorded in treatments inoculated with EM under higher planting density, indicating that microbial activity may contribute to reducing competition stress among plants under intensive cultivation conditions. Regarding yield components, capsule length did not differ significantly among treatments, although slightly higher values were observed in treatments inoculated with T. *harzianum*. Similar findings were described by Montoya et al. (2019), who reported moderate effects of biological fertilization on reproductive structures in sesame. In contrast, the number of capsules per plant increased significantly in treatments with *T. harzianum*, particularly when combined with EM at higher planting density. This response may be associated with improvements in nutrient uptake efficiency and greater physiological activity promoted by beneficial microorganisms. According to Oyesola et al. (2024) and Monte (2023), Trichoderma spp. can enhance plant performance through mechanisms related to nutrient mobilization, antagonism against phytopathogens, and stimulation of root growth. Grain yield was the variable with the greatest response to microbial inoculation. Significant effects were observed for the application of T. *harzianum* and for its interaction with EM. The highest grain yield (1,252 kg ha^{-1}) was obtained under the treatment combining *T. harzianum* with the higher planting density. These results are consistent with previous studies reporting positive effects of biological inoculation on sesame productivity under tropical conditions (Carreño and Rojas, 2013; Melgarejo et al., 2020). The positive interaction between T. *harzianum* and EM may be related to improved nutrient availability, enhanced root activity, and greater tolerance to biotic and abiotic stress, as previously described by Poveda (2021) and Caccavo et al. (2022). From an agronomic perspective, the results support the use of biological management strategies as an alternative for improving sesame productivity under tropical conditions. Previous studies have shown that integrating microbial inoculation with cultural management practices contributes to reducing pest incidence and improving crop performance (Mishra et al., 2021; Alemu and Taye, 2022; Sheeba Jasmine et al., 2020). However, information regarding the combined effect of planting density, Trichoderma, and EM under open-field conditions in the Peruvian Amazon remains limited. In this context, further studies should include longer evaluation periods, soil microbiological characterization, and physiological analyses to better understand the interactions between beneficial microorganisms and sesame crop performance under humid tropical environments.

Conclusions

The application of *Trichoderma harzianum* and Effective Microorganisms (EM) influenced the agronomic performance of Sesame under humid tropical conditions. Plant height and grain yield showed the greatest response to microbial inoculation, particularly under the interaction between T. harzianum and higher planting density. The highest grain yield reached 1,252 kg ha^{-1}, while treatments inoculated with *T. harzianum* also presented higher numbers of capsules per plant compared with non-inoculated treatments.In contrast, reproductive height and capsule length did not show significant differences among treatments, suggesting that these variables may be more strongly associated with varietal characteristics and environmental conditions than with microbial application. The results indicate that the use of biological inoculants can contribute to improving sesame productivity under tropical field conditions, especially when combined with appropriate crop management practices. The study was limited to a single production cycle and did not include soil microbiological characterization or rhizosphere analyses. Therefore, future research should evaluate the long-term effects of microbial inoculation under different environmental conditions and planting systems. Additional studies focused on microbial interact-tions, nutrient dynamics, and strain compatibility could improve the understanding of the role of beneficial microorganisms in sustainable sesame production in the Peruvian Amazon.

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