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Dual Function Organomineral Formulations: Fertilization and Carrier for *Trichoderma harzianum* in Banana Plants

Gelton G. F. Guimarães, André B. Beltrame, Alexandre Visconti, Amanda S. Giroto, Roger Borges, Cristiane S. Farinas, and Caue Ribeiro*

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ABSTRACT: This study reports the development and performance evaluation of a bioactive organomineral fertilizer enriched with *Trichoderma harzianum* to stimulate early growth of banana plants (*Musa* spp.) under controlled greenhouse conditions. The fertilizer pellets were formulated using agroindustrial residues and sterilized reactive rock phosphate as the carrier matrix into which viable propagules of *T. harzianum* were incorporated. Microbial viability remained above 1×10^5 CFU g^{-1} after pelletization and drying, confirming process compatibility with biological stability. Greenhouse assays with micropropagated banana cv. Grande Naine demonstrated a pronounced synergistic interaction between the bioagent and the organomineral matrix. The integration of *T. harzianum* with the complete (100%) organomineral dose increased plant height by 18% and total fresh biomass by 39% compared with the same fertilization rate without the fungus, an effect equivalent to more than double the fertilizer application rate. In contrast, such synergy was absent with conventional mineral fertilizers, whose high solubility hindered microbial activity. Increasing the organomineral dose yielded linear growth responses, indicating a gradual nutrient release pattern. These findings highlight the potential of this bioactive organomineral formulation as a sustainable fertilizer technology that couples organic residue valorization, mineral nutrient recycling, and microbial bio stimulation to improve nutrient use efficiency and reduce reliance on synthetic inputs.

KEYWORDS: *biofertilizers, bioagents, phosphorus solubilization, plant nutrition, soil health*

1. INTRODUCTION

The global demand for food requires agriculture to increase productivity, which is both sustainable and economically viable. Worldwide fertilizer consumption reached nearly 200 million tonnes of nutrients in 2024, with phosphate alone around 46.7 million tons.[1] However, production is highly concentrated, with China, Morocco, the United States, and Russia accounting for almost 80% of the global phosphate output, which leads to concerns over supply security and price volatility.[2] Recent analyses also highlight declining fertilizer access, due to higher costs and market instability.[3] To address these challenges, international initiatives such as FAO's INSOILFER network promote sustainable fertilizer use and the development of alternatives, including organomineral fertilizers, biofertilizers, and biotechnologies to improve nutrient efficiency and reduce environmental impacts.[4]

In this context, the search for solutions that integrate the reuse of agroindustrial residues with the bioactivation of agricultural inputs has gained increasing relevance. One promising approach involves the use of phosphorus-solubilizing microorganisms (PSMs), which can enhance phosphorus availability in soils through mechanisms such as the production of organic acids (gluconic, citric, and oxalic), the release of enzymes (phosphatases and phytases), and the secretion of protons and siderophores, thereby promoting the solubilization of inorganic and organic phosphorus compounds.[5,6] Among the most extensively studied PSMs are bacterial genera such as *Bacillus*[7,8] and *Pseudomonas*,[9,10] as well as fungi including *Aspergillus niger*[11,12] and *Trichoderma harzianum*.[13] The fungus *Trichoderma harzianum* is particularly notable for its biostimulatory effects and its role in the biological control of soilborne diseases. Studies have shown that coating phosphate sources, such as rock phosphate and triple superphosphate, with *T. harzianum* can enhance soil enzymatic activity, reduce pH, and significantly increase phosphorus uptake and plant biomass, as observed in maize cultivation.[13]

In parallel, organic residues from agroindustrial activities, for example, animal manure, byproducts of food processing, and animal-based meals, hold considerable potential as sources of organic matter and nutrients. However, their direct application to soil may be limited by the variability in composition, low nutrient density, sanitary risks, and operational constraints. Therefore, it is necessary to qualify these residues through physical, chemical, and biological processes. The addition of mineral sources enriches their nutrient content; pelletization or extrusion improves product uniformity, stability, and ease of application[14] and the incorporation of beneficial microorganisms adds biological functionality, enhancing plant growth, nutrient solubilization, and the suppression of phytopathogens.[11,15] These bioactive organomineral fertilizers have emerged as an innovative class of multifunctional

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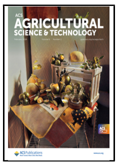

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agricultural inputs that combine mineral nutrients, organic matter, and plant growth-promoting microorganisms. These products not only supply essential nutrients but also improve soil structure and biological activity, enhancing nutrient use efficiency and crop resilience to both biotic and abiotic stresses.

Despite its potential, incorporating beneficial microorganisms into solid formulations, such as granules or pellets, remains a technical challenge, particularly in terms of maintaining microbial viability during processing and ensuring gradual release in the soil. Strategies such as microbial encapsulation have gained attention for providing protection against environmental stresses and enabling controlled release in the rhizosphere.[11,16] The combination of encapsulation and pelletization using agroindustrial residues and mineral sources offers a promising route for the development of bioactive organomineral fertilizers.[17−19] This approach promotes synergy between plant nutrition and protection, aligning with the principles of bioeconomy and circular economy by valorizing residues as raw materials and adding biotechnological value to the final product.[20] Fertilizers with physical characteristics suitable for mechanized application and enhanced biological activity contribute to the sustainable management of agricultural systems.[15,21]

Nevertheless, significant knowledge gaps remain, particularly regarding the standardization of *Trichoderma* spp.-based pelletized formulations, the integrated evaluation of their physicochemical and biological properties, and the assessment of crop responses, especially economically important species such as banana (*Musa* spp.), under controlled conditions. Factors such as matrix component compatibility, substrate microbiota, application method, dosage, exposure duration, and reapplication frequency can all critically influence the product efficacy.

Therefore, this work aimed to develop and evaluate a novel bioactive organomineral fertilizer formulated with *Trichoderma harzianum* as a functional bioagent. The proposed formulation integrates agroindustrial residues and reactive mineral phosphate into a pelletized matrix capable of maintaining microbial viability and providing gradual nutrient release. Through physicochemical, structural, and morphological characterization as well as greenhouse assays with banana (*Musa* spp.) seedlings, this study sought to investigate the synergistic effects between the organomineral matrix and *T. harzianum* on plant growth, nutrient use efficiency, and soil biological activity, establishing a sustainable and scalable route for multifunctional fertilizer production.

2. MATERIALS AND METHODS

2.1. Material Preparation

In this study, a novel route was proposed for the pelletization of organomineral fertilizers with active formulations of *Trichoderma* sp. Strains of *T. harzianum* LQC-99 from Embrapa, stored at −80 °C in a solution of 30% glycerol and 0.9% NaCl, were cultured on potato dextrose agar (PDA) at 25 °C, 12 h light for 7 days. Then, ten agar plugs (5 mm diameter) of the active mycelium from the PDA plates were transferred to cooked rice and incubated under the same conditions for 1 week. After propagation, conidia quantification was performed on the rice substrate, yielding an average concentration of 3.6×10^8 spores g^{-1} rice. The entire rice substrate containing the fungus (46% moisture) was pelletized with autoclaved reactive mineral phosphate (28% P_2O_5 and 3% moisture) in two ratios (w/w): 50% rice:50% mineral phosphate and 30% rice:70% mineral phosphate. The mixtures (50/50 with 30% moisture and 30/70 with 20% moisture), in batches of 5 kg, were processed in a ring-die pelletizer with 4 mm perforations (model: Chavantes 12 W, 7.5 HP, processing capacity 100 kg h^{-1}). Figure 1 illustrates the main stages of the process, including the *T. harzianum* culture grown on rice, the solid mixture prepared for pelletization, the pelletizing device, and the final organomineral pellets containing the bioagent.

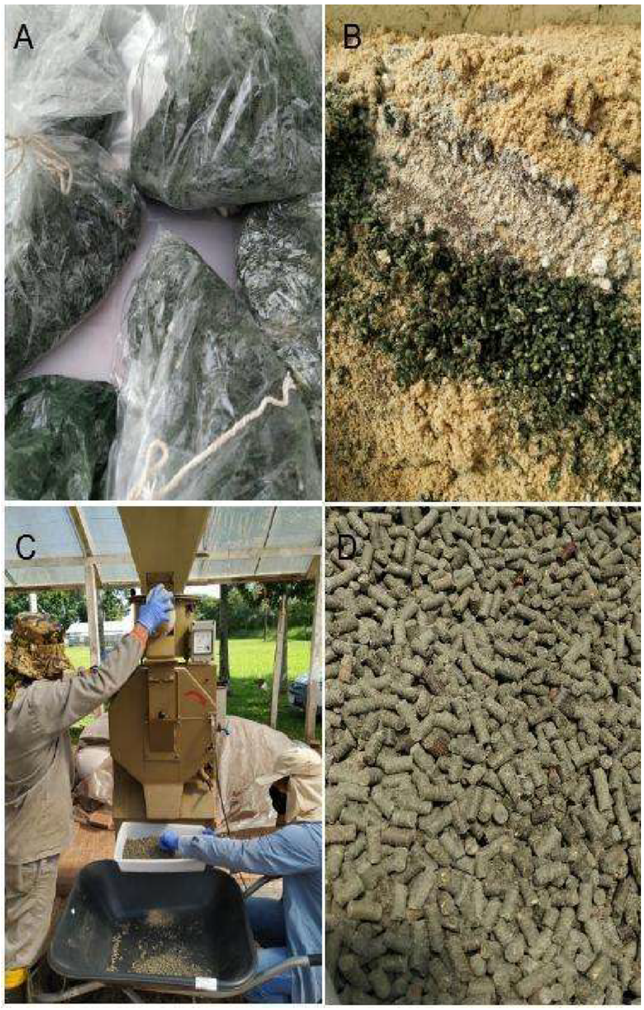

Figure 1. Bioactive matrix of *T. harzianum* (A), mixture for pelletization (B), pelletizing device (C), and organomineral pellets containing *T. harzianum* (D).

After processing, the pellets were dried at 30 °C in a forced-air circulation oven for 8 h until they reached approximately 7.5% moisture. The concentration of *T. harzianum* was determined in both wet and dry pellets by decimal serial dilutions (Table 1).

Pelletization was also performed for an organomineral fertilizer composed of swine manure residues, bovine hoof and horn meal (containing 15% N), and mineral potassium sulfate (50% K_2O). The raw materials were previously homogenized and processed under the

Table 1. Concentration of *T. harzianum* in Dry or Wet Pellets Composed of Rice and Autoclaved Mineral Phosphate in Two Proportions

rice/MP ratio	concentration of *Trichoderma* sp. (CFU g^{-1} pellets)	
%	wet	dry
50/50	1×10^7	1×10^5
30/70	5×10^5	$<1 \times 10^4$

same conditions described above with a mixture moisture content of approximately 15%. Certified raw materials suitable for use in organic farming were prioritized and combined in proportions that meet the nitrogen, phosphorus, and potassium (N−P−K) nutritional requirements of banana crops. After pelletization, the organomineral fertilizer showed NPK concentrations of 3.0, 1.5, and 7.0%, respectively.

2.2. Characterization Analyses

Samples of the cooked rice matrix, reactive phosphate, and dried bioactive pellets were characterized to evaluate their chemical, structural, and morphological features.

Fourier transform infrared (FTIR) spectra were recorded using a Bruker Vertex 70 spectrometer in the range of 4000−400 cm^{-1}, with a spectral resolution of 4 cm^{-1} employing the KBr pellet method. The crystalline phases of the samples were determined by X-ray diffraction using a Shimadzu diffractometer equipped with Cu Kα radiation (λ = 1.5406 Å). Data were collected over a 2θ range of 5−70°, with a step size of 0.02° and a scanning speed of 2° min^{-1}. Surface morphology and microstructural characteristics were examined by using a JEOL scanning electron microscope (SEM). Samples were mounted on aluminum stubs with double-sided carbon tape, coated with a thin layer of gold under a vacuum, and imaged at various magnifications. The image was treated using Gimp (GNU Image Manipulation Program) software. Three-dimensional structural analyses were conducted using a microtomography system (SkyScan model 1172). The pellets were scanned in a rotating steel holder with a voxel size of 2 μm, a rotation step of 0.3°, and an average of six frames per projection. The reconstructed images were generated using NRecon software with the following parameters: smoothing = 5, ring artifact correction = 5, and beam hardening correction = 60%. The resulting tomograms were analyzed to quantify the pore connectivity, internal density distribution, and overall structural compaction of the pellets.

2.3. Greenhouse Experiments

The agronomic evaluation of the organomineral fertilizer, as well as the effect of *T. harzianum* inoculation, soil microbial activity, and the initial development of banana plants, was assessed after four months of cultivation under controlled conditions. Micropropagated banana seedlings (cv Grande Naine) were transplanted into pots containing 6 kg of soil and fertilized with different doses of the organomineral fertilizer, with or without *T. harzianum*. The effect of the microorganism was also analyzed in comparison with chemical/synthetic fertilizers. The compositions of the treatments are presented in Table 2.

The clay content and the chemical parameters of the soil are presented in Table 3. To correct soil acidity and increase base saturation to 75%, a lime dose equivalent to 1 t ha^{-1} was applied with a total relative neutralization power (TRNP) of 80%. Three weeks after soil conditioning, the fertilizer doses, either mixed or not with pellets containing *T. harzianum*, according to the treatments described in Table 2, were incorporated into 6 kg of soil, which was subsequently placed in plastic pots.

After fertilizer application, one banana seedling was transplanted per pot. The experiment was conducted in a completely randomized design with seven replicates, with 56 experimental units. Plant irrigation was performed manually using a watering can as needed. The seedlings were cultivated for a period of four months, and pellets containing *T. harzianum* were reapplied during the following three months on the soil surface of the corresponding pots according to the treatments (Figure 2).

At the end of the cultivation period, the plant height and shoot biomass of the banana plants were measured. Soil samples were also collected to determine arylsulfatase and β-glucosidase activities, according to Tabatabai.[22] The Shapiro−Wilk test (error normality) and Bartlett's test (homogeneity of variance) were performed using R software and the ExpDes.pt package. Data were analyzed by parametric tests (analysis of variance (ANOVA) and Scott−Knott mean comparison test, ExpDes.pt package) or by nonparametric tests (Kruskal−Wallis test, stats package, and Conover−Iman multiple comparisons [5%], Conover. Test package).

Table 2. Composition of the Treatments Evaluated in the Pot Experiment

treatments	fertilizer dose (g/pot)	N−P−K dose (mg/kg soil)	pellets containing *T. harzianum* (g/pot)[a]
control	0	0	0
T. harzianum control	0	0	150
mineral 100%	urea[b] (2.0); TSP[c] (1.1); KCl[d] (3.5)	150−75−350	0
mineral 100% + *T. harzianum*	urea (2.0); TSP (1.1); KCl (3.5)	150−75−350	150
organomineral 50%	15	75−37.5−175	0
organomineral 100%	30	150−75−350	0
organomineral 100% + *T. harzianum*	30	150−75−350	150
organomineral 200%	60	300−150−700	0

[a]Concentration of *T. harzianum* 1×10^5 (CFU g^{-1} of pellets). [b]Urea (45% N). [c]Triple superphosphate (41% P_2O_5). [d]Potassium chloride (60% K_2O).

3. RESULTS AND DISCUSSION

Understanding the mineral composition of the phosphate source is essential for interpreting its behavior in the formulation. The FTIR spectra and XRD data of the phosphate showed that the main mineral was apatite ($Ca_{10}(PO_4)_6(OH, F, Cl)_2$) (Figure 3). However, natural sources of apatite usually contain other minerals and impurities, such as calcium carbonate, quartz, and limestone, among others, which explain the additional signals observed.[23] The material composed of rice with *Trichoderma* exhibits the characteristic signals of rice starch.[24,25] The characteristic peaks in the X-ray diffractogram indicate that the crystalline structure of starch is preserved even after the autoclaving process and the cultivation of *Trichoderma*.[26] As expected, the FTIR spectra and XRD data of the pellets show an overlap of the signals of their main components, namely, phosphate rock apatite and rice starch with *T. harzianum*.

From the SEM images, it is possible to observe a uniform distribution of phosphate rock particles in the rice matrix containing *T. harzianum* (Figure 4). Phosphate rock particles have a smoother surface; however, there is no apparent morphology pattern. Most of the particles are rounded, and some of them have defined straight edges. The rice matrix containing *T. harzianum* has a more porous morphological pattern with considerable uniformity and cracks. From the SEM images and using the ImageJ software, the average particle distribution size was also estimated, finding particles ranging from larger particles measuring 420 μm to smaller particles measuring around 90 μm. However, in this analysis, the particle size of phosphate rock may be underestimated, as the rice matrix may partially cover the particles. The images at different magnifications show the rice matrix with *T. harzianum* in a green tone and the phosphate rock in a red tone.

The X-ray microscopy images corroborate the SEM results. Phosphate rock is denser and stands out from the starch matrix in the white contrast seen in Figure 5. As observed by SEM, the phosphate rock particles are well-dispersed in the matrix and present quite varied particle sizes and shapes with a predominance of rounded particles. It is also possible to

Table 3. Chemical Parameters of the Soil Used in the Pot Experiment

clay	pH[a]	P	K	OM[b]	m[c]	V[d]	Al	Ca	Mg	H + Al	CEC[e]
%		mg dm^{-3}		%			cmol$_c$ dm^{-3}				
27	5.8	12	10.8	3.7	0.0	52.5	0.0	0.9	1.0	1.7	3.7

[a] pH in water. [b] Organic matter. [c] Aluminum saturation. [d] Base saturation. [e] Cation exchange capacity at pH 7.

Figure 2. Arrangement of the pots containing the treatments (A) and detail of the seedling fertilized with organomineral pelleted with *T. harzianum* (B), with signs (white and green mycelia) of the fungus growing on the surface of the pellets.

observe the presence of large pores and cracks, an interesting characteristic for matrices containing microorganisms in agricultural applications, as it allows for easy permeation of air and water. This would facilitate, for example, the disaggregation of the matrix and growth of *T. harzianum* cells.

Figure 6 shows the effect of mineral fertilization (from mineral and synthetic sources) and organomineral fertilization, either associated or not with *T. harzianum*, on the development of banana seedlings over four months of cultivation. As expected, plants that did not receive fertilization exhibited significantly lower height and biomass compared to fertilized plants, highlighting the importance of nutrient supply for the proper initial growth of the banana. However, even in the absence of fertilization, the application of pelletized *T. harzianum* to the soil promoted an increase in seedling development, indicating the potential of this bioagent as a plant growth promoter (Figure 7). This effect can be attributed to the ability of the bioagent to stimulate root development, produce phytohormones (such as auxins and gibberellins), and solubilize soil nutrients, thereby increasing their availability to plants even under low-fertility conditions. These results corroborate previous studies reporting the beneficial effect of

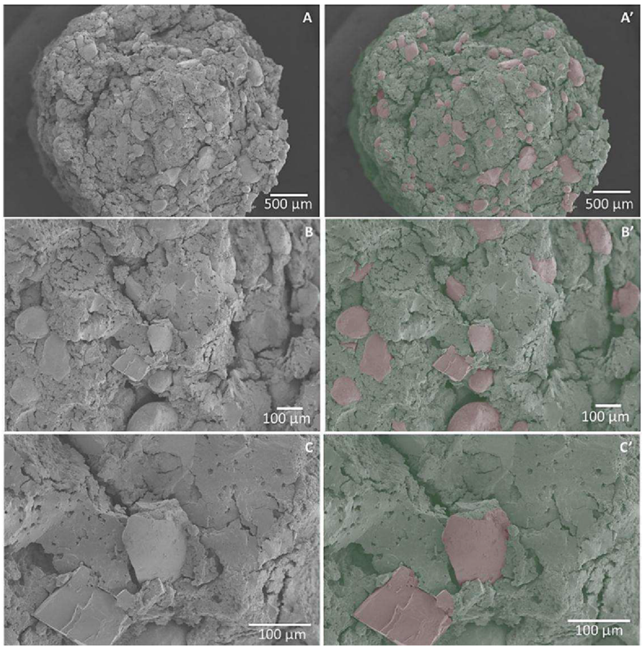

Figure 4. SEM images of the pellet formed by phosphate rock and rice with *T. harzianum* at three different magnifications (A), (B), and (C), and their colorized versions, highlighting phosphate rock in red tone and rice with *T. harzianum* in green tone ((A′), (B′), and (C′)).

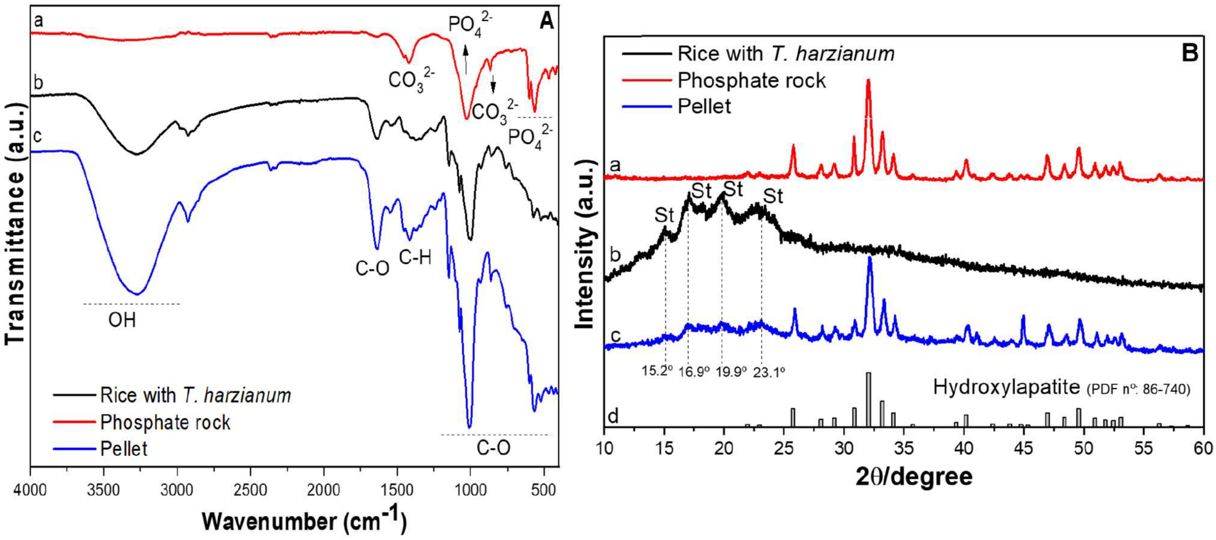

Figure 3. FTIR spectra (A) and XRD data (B) of the phosphate rock, rice with *T. harzianum*, and pellet formed by phosphate rock and rice with *T. harzianum*.

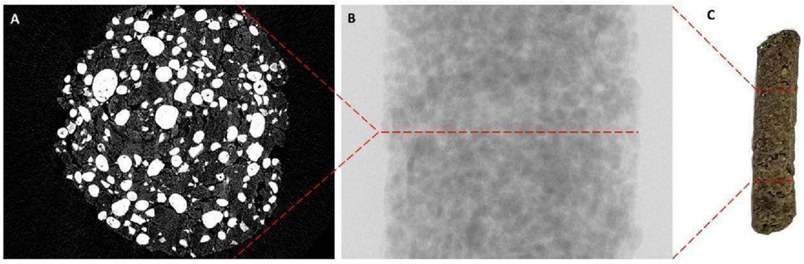

Figure 5. X-ray microtomography images of the pellet formed by phosphate rock and rice with *T. harzianum*.

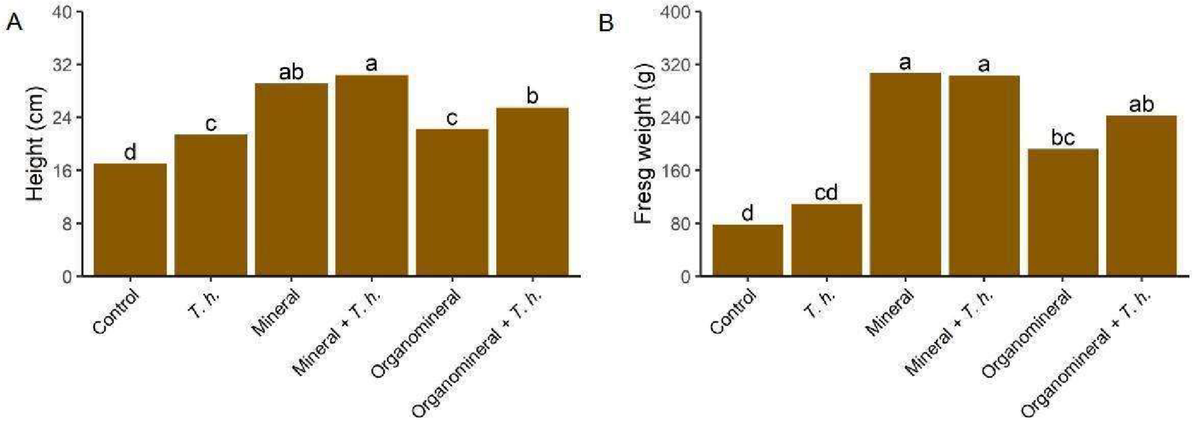

Figure 6. Height (A) and fresh biomass (B) of banana seedlings after four months of cultivation as a function of treatments: Control (no fertilizer and no *T. harzianum*); *T. h.* (no fertilizer, but with pelletized *T. harzianum*); mineral (100% mineral source dose); mineral + *T. h.* (100% mineral source dose and pelletized *T. harzianum*); organomineral (100% organomineral source dose); and organomineral + *T. h.* (100% organomineral source dose and pelletized *T. harzianum*). Means followed by the same letter within a column do not differ according to the Kruskal−Wallis test ($p < 0.01$).

Figure 7. Seedlings before evaluation (from left to right): control (no fertilizer and no *T. harzianum*); *T. h.* (no fertilizer, but with pelletized *T. harzianum*); mineral + *T. h.* (100% mineral source dose and pelletized *T. harzianum*); and organomineral + *T. h.* (100% organomineral source dose and pelletized *T. harzianum*).

T. harzianum on the growth of different crops, especially in soils with low nutrient availability.[27]

Overall, an increase in plant height and biomass was also observed in seedlings fertilized with organomineral fertilizers containing *T. harzianum* compared with those treated with organomineral alone. This response can be attributed to the synergistic interaction between the bioagent and the organomineral matrix. In contrast, no additional effect of pelletized *T. harzianum* was observed in plants receiving exclusively mineral fertilization. The mineral sources used, as described in Table 2, exhibit high solubility, providing immediate nutrient availability to the plants. Thus, the potential contribution of the bioagent to nutrient release may have been masked by the ready availability afforded by mineral fertilization, resulting in a marginal or absent effect of the microorganism under these conditions. This finding suggests that the benefits of associating *T. harzianum* are more evident under conditions of limited immediate nutrient availability, as observed with organomineral fertilizers.

As shown, mineral sources promoted greater seedling development compared with the organomineral source, a result directly linked to the chemical nature of the nutrients supplied. While nutrients in mineral fertilizers are readily available, those in organomineral fertilizers depend partly on biological processes, such as organic matter mineralization and solubilization of less soluble mineral fractions. This behavior aligns with the literature, which emphasizes the gradual nutrient release characteristic of organomineral fertilizers.[28] Although this may represent an agronomic advantage in the medium and long term, it restricts the immediate response of plants compared with mineral sources.

The effect of different organomineral fertilizer doses on early banana development is assessed in Figure 8. Both plant height and biomass increased linearly with the applied doses, indicating that the crop would likely respond positively to nutrient levels higher than those tested in this study. This suggests that the doses used, although corresponding to 100% of the recommended rate, may have underestimated the actual nutritional demand of the crop under the experimental conditions. This likely reflects the fact that a fraction of the nutrients in the organomineral formulation is not immediately available for plant uptake. Thus, it becomes evident that a correction factor should be established to account for the differentiated nutrient availability in organominerals, ensuring adequate supply throughout the crop cycle. Furthermore, the results shown in Figure 8 confirm the positive effect of

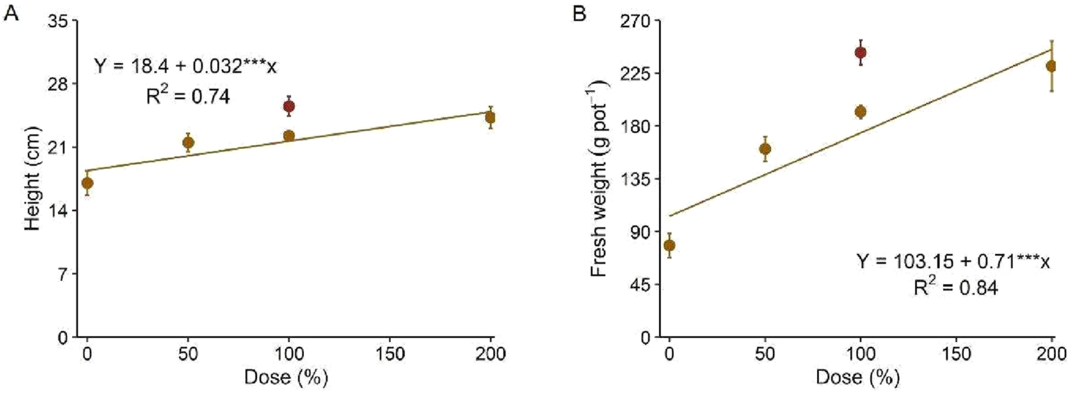

Figure 8. Height (A) and fresh biomass (B) of banana seedlings after four months of cultivation as a function of organomineral fertilizer doses. The combination of pellets containing *T. harzianum* with organomineral fertilizer pellets was evaluated only at the 100% dose. Error bars represent standard deviations.

pelletized *T. harzianum*, even when applied together with the full (100%) dose of organomineral fertilizers.

The presence of *Trichoderma harzianum* associated with organomineral fertilizers at the 100% dose promoted an increase of 18% in plant height and 39% in fresh biomass production compared with fertilization at the same dose without the bioagent (Table 4). Considering the effect observed in these parameters, the presence of the bioagent is equivalent to an organomineral dose of 222% for height and 196% for fresh biomass. In other words, substantially higher amounts of organomineral fertilizers would be required to achieve the same growth obtained when the fertilizer is combined with *T. harzianum*.

Table 4. Adjusted Model for Plant Height and Fresh Biomass (F.B.) as a Function of Organomineral Doses[a]

		organomineral (100%)			
parameter	model	without *T. hazianum*	with *T. hazianum*	increment %	equivalent dose %
height (cm)	$y = 18.4 + 0.032X$	21.6	25.5	18.1	221.9
F.B. (g/pot)	$y = 103.15 + 0.71X$	174.2	242.6	39.3	196.5

[a] Parameter values in the presence or absence of *T. harzianum* combined with the organomineral at the 100% dose; seedling growth increase and equivalent organomineral dose required to achieve the same production as that obtained with organomineral plus *T. harzianum*.

This additional increase highlights the potential of the bioagent as a complementary technology to fertilization, especially in systems that employ controlled or slow-release sources such as organominerals. The action of *T. harzianum* may be associated with enhanced solubilization and availability of nutrients in the soil as well as with the promotion of a biologically more active rhizosphere environment. Together, these processes contribute to greater nutrient uptake efficiency and result in more vigorous early plant development. Such results reinforce the role of bioproducts as strategic allies in nutrient management while also enabling a reduction in the dependence on high doses of mineral fertilizers, thus aligning with sustainable agricultural practices.

In summary, the results indicate that the association of *T. harzianum* with organomineral fertilizers may represent a promising strategy to enhance the early growth of banana plants, especially in systems with lower immediate nutrient availability. This approach also aligns with the principles of sustainable agriculture by integrating the use of organic residues, alternative mineral sources, and beneficial microorganisms, promoting greater resource-use efficiency and reducing dependence on synthetic inputs.

Regarding soil enzymatic activity, no significant differences were observed in arylsulfatase and β-glucosidase activity among treatments with mineral fertilizers, organominerals, or *T. harzianum* application (Figure S1). No effect of organomineral doses was observed either (Figure S2). These enzymes are associated with sulfur cycling and the degradation of organic polysaccharides, respectively, and are indicators of microbial activity and soil biological quality.[29] It was expected that the organic fraction of the organomineral fertilizer, combined with the introduction of a bioagent, such as *T. harzianum*, would stimulate soil enzymatic activity. The absence of this effect may be related to the short cultivation period (four months), which was insufficient to detect significant changes in the soil microbiota and associated enzymatic activities.

This study demonstrated that bioactive organomineral fertilizers incorporating *Trichoderma harzianum* represent an effective and sustainable alternative for enhancing early banana growth, while improving nutrient use efficiency. The structural and morphological analyses confirmed the good integration of mineral phosphate within the organic rice-based carrier and the compatibility of the pelletization process with microbial viability. Greenhouse assays revealed that the combination of *T. harzianum* with the organomineral matrix significantly promoted plant height and biomass compared to fertilization alone, evidencing a synergistic interaction between the bioagent and the slow-release nutrient matrix. In contrast, the absence of additional effects under mineral fertilization highlights that the benefits of microbial inoculation are most pronounced when nutrient availability is gradual, as in organomineral systems. The linear plant growth response to increasing organomineral doses reinforces the controlled-release characteristics of the formulation and its potential for fine-tuning nutrient supply. Overall, this dual-function organomineral fertilizer couples the recycling of agroindustrial residues with biological activation, contributing to the circular bioeconomy and reducing dependence on synthetic fertilizers. The results establish a technological foundation for scaling up the production of bioactive pellets and expanding their application to other crops and field conditions, supporting more resilient and environmentally efficient agricultural systems.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsagscitech.5c01011.

> Soil arylsulfatase and β-glucosidase activities after banana cultivation under mineral and organomineral fertilization, with and without *Trichoderma harzianum*, as a function of fertilization strategy and organomineral dose (Figures S1 and S2) (PDF)

■ AUTHOR INFORMATION

Corresponding Author

Caue Ribeiro − *Embrapa Instrumentation, São Carlos, São Paulo 13560-970, Brazil;* orcid.org/0000-0002-8908-6343; Email: caue.ribeiro@embrapa.br

Authors

Gelton G. F. Guimarães − *Agricultural Research and Rural Extension Company of Santa Catarina (EPAGRI), Itajaí, Santa Catarina 88318-112, Brazil;* orcid.org/0000-0001-9029-5241

André B. Beltrame − *Agricultural Research and Rural Extension Company of Santa Catarina (EPAGRI), Itajaí, Santa Catarina 88318-112, Brazil*

Alexandre Visconti − *Agricultural Research and Rural Extension Company of Santa Catarina (EPAGRI), Itajaí, Santa Catarina 88318-112, Brazil*

Amanda S. Giroto − *Science and Technology Institute, Federal University of São Paulo, São Paulo, São Paulo 12231-280, Brazil*

Roger Borges − *Department of Chemistry, Federal Technological University of Paraná, Medianeira, Paraná 85884-000, Brazil;* orcid.org/0000-0001-6992-3717

Cristiane S. Farinas − *Embrapa Instrumentation, São Carlos, São Paulo 13560-970, Brazil;* orcid.org/0000-0002-9985-190X

Complete contact information is available at:
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Author Contributions

G.G.F.G.: methodology, research, formal analysis, data curation, and writing-original draft. A.B.B.: visualization, methodology, conceptualization, formal analysis, data curation, and writing-original draft. A.V.: visualization, methodology, and research. A.S.G.: visualization, methodology, research, formal analysis, and writing-revision and editing. R.B.: visualization, methodology, and writing-original draft. C.F.: writing-revision and editing, supervision. C.R.: writing-proofreading and editing, supervision, resources, data curation, and conceptualization.

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Notes

The authors declare no competing financial interest.

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