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COMPATIBILITY BETWEEN GROWTH-PROMOTING MICROORGANISMS AND CHEMICAL MANAGEMENT IN THE EARLY DEVELOPMENT OF MAIZE

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Abstract: The objective of this study was to evaluate the compatibility between biological and chemical products used in seed treatment, with an emphasis on inoculants and plant growth promoters. The research was conducted in two stages: in vitro assays, performed in Petri dishes with BDA (Potato-Dextrose-Agar) medium, and assays in Gerbox-type chambers, using commercial substrate treated with herbicides. In the in vitro assay, five biological microorganisms (*Azospirillum* sp., *Bacillus sp.*, *Pseudomonas* sp., *Trichoderma* sp., and *Paecilomyces lilacinus*) were exposed to fungicides and herbicides, and microbial growth was assessed after 72 hours of incubation. The results indicated that *Azospirillum* sp. and *Bacillus* sp. showed tolerance, maintaining positive growth, while *Pseudomonas* sp., *Trichoderma* sp., and *Paecilomyces lilacinus* demonstrated sensitivity, with an absence or significant reduction in development. In Gerbox trials, conducted at different time points after herbicide application (15, 30, and 45 days), it was observed that treatments with *Bacillus sp.* and *Pseudomonas* sp. promoted greater leaf length and better initial performance of corn plants, outperforming the control and the treatment with *Paecilomyces lilacinus*. These results reinforce that compatibility between biological and chemical products is variable and depends on the microbial species and the active ingredient used. It is concluded that *Bacillus* sp. and *Pseudomonas* sp. have greater potential for integration into agricultural systems, contributing to more sustainable and efficient practices in seed and soil management.

Keywords: *Bacillus*. Bio-inputs. Fungicides. Herbicides. *Pseudomonas*.

INTRODUCTION

Modern agriculture faces the challenge of reconciling high productivity with sustainable practices, reducing environmental impacts, and ensuring the quality of the food produced. In this context, the use of biological products, such as inoculants and growth promoters, has emerged as a viable alternative for agricultural management, especially in crops of great economic importance, such as soybeans and corn.

These microorganisms contribute primarily to plant development through biological nitrogen fixation, nutrient solubilization, and the induction of systemic resistance, making them important allies in more balanced production systems. In recent decades, various studies have shown that the microorganisms used as biological inputs play a decisive role in optimizing nutrient uptake by plants and strengthening their ability to withstand biotic and abiotic stresses (FRONTIERS et al., 2021).

This set of benefits has driven the use of these products in high-productivity agricultural systems. At the same time, advances in biotechnology have enabled the development and selection of more efficient microbial strains adapted to different growing environments, which broadens their applicability and reinforces their importance as a sustainable alternative to reduce dependence on chemical fertilizers and other synthetic inputs (STEFAN et al., 2023).

However, the large-scale adoption of biological products still faces limitations related to their compatibility with chemical pesticides, such as fungicides and herbicides, which are widely used in seed treatment and agricultural land management. The interaction between these inputs can compromise the viability of microorganisms, reducing their efficiency and hindering the integration of biological technologies into conventional systems.

Given this reality, it is essential to assess which combinations of biologicals and chemicals are viable, in order to guide producers and technicians in the appropriate selection of inputs. Therefore, the present study aimed to: (1) evaluate the compatibility between different microbial inoculants and fungicides in *in vitro* assays; and (2) verify the residual effect of herbicides on plant growth-promoting microorganisms in Gerbox chambers. In this way, we sought to generate applicable knowledge for the integrated adoption of biological and chemical technologies, contributing to more efficient production systems

METHODOLOGY

The experiment was conducted at the Microbiology Laboratory of the State University of Goiás – Palmeiras de Goiás Campus, in the municipality of Palmeiras de Goiás, in 2025. Two types of experiments were carried out: the first was an *in vitro* experiment using the paired-sample method, and the second involved seedlings in Gerbox-type chambers.

In vitro compatibility test

In the *in vitro* test, sterile Germitest paper strips were soaked in different fungicides and herbicides, as well as in solutions of inoculants and growth promoters (Table 1). After soaking, the strips were drained and placed on BDA (Potato-Dextrose-Agar) culture medium in Petri dishes.

Biological	*- Inoculants: Liquid – Paecilomyces lilacinus (T1)* *- Growth promoters: Azospirillum* sp. *(T2), Bacillus* sp. *(T3), Trichoderma* sp. *(T4), Pseudomonas* sp. *(T5)*
Chemical products	*- Fungicide / Seed treatment*: Carboxanilide + Dimethyldithiocarbamate *- Herbicides - Corn:* Glyphosate (pre-emergent) Cletodim (post-emergent)

Table 1 - Biological and chemical products used for the compatibility test – *in vitro* test.

Source: authors.

The plates were incubated in BOD for 72 hours. After this period, the presence (+) or absence (–) of microbial growth was determined, and when positive, the thickness of the colonies was measured. Each microorganism constituted a treatment, with the experimental design being a randomized block design in a 5 (biological) × 3 (chemical) × 4 (replications) factorial scheme. The collected data were subjected to analysis of variance (ANOVA), and when significant, the means were compared using the Scott--Knott test at a 5% probability level.

Gerbox-type chamber seedling trial

For the Gerbox-type chamber trial, the chambers were sanitized with sodium hypochlorite and, after drying, 80% of the volume was filled with commercial substrate. Subsequently, they received applications of the herbicides (Table 1) at the concentrations recommended by the manufacturer. Sowing of corn inoculated with the treatments *Paecilomyces lilacinus* (T1), *Bacillus* sp. (T3), *Pseudomonas* sp. (T5), and the control (ST) (Table 1) was performed 15, 30, and 45 days after spraying (DAS).

The chambers were maintained under ambient conditions for 10 days. After this period, the substrate and root system were evaluated. For the substrate, the serial dilution isolation technique was used; for the root system, the rootlets were washed, followed by identification and quantification of colony-forming units (CFU). The experimental design was a randomized block design, in a 3 (biological) × 2 (chemical) × 3 (time) factorial scheme, with four chambers per treatment and six seeds per chamber, totaling 15 replicates. The data were analyzed by ANOVA, and when significant, the means were grouped using the Scott-Knott test at a 5% probability level.

Statistical Analysis

Statistical analysis was performed using the Sisvar software, and means were compared using the Scott-Knott test at a 5% probability level.

RESULTS AND DISCUSSION

The results obtained from the analysis of variance are presented in Table 2, which allowed for an evaluation of the compatibility between biological and chemical products used in seed treatment, as well as the effects of herbicides on inoculant microorganisms.

In the *in vitro* assay, compatibility was found to vary depending on the microorganism tested. *Azospirillum* sp. and *Bacillus* sp. showed positive growth, indicating tolerance to the applied fungicide. In contrast, *Pseudomonas sp.*, *Trichoderma* sp., and *Paecilomyces lilacinus* demonstrated sensitivity, with an absence or significant reduction in growth.

The positive growth of *Azospirillum* sp. suggests tolerance of the strain used, differing from results such as those of Halfeld

Treatments	Variables					
	CPA	MFPA	MSPA	CRAIZ	MFRAIZ	MSRAIZ
ST	23.9 C	0.98 A	0.069 A	20.03 A	0.66 A	0.04 A
T1	26.1 B	1.04 A	0.069 A	22.83 A	0.35 B	0.03 B
T3	28.5 A	1.09 A	0.070 A	21.96 A	0.43 B	0.03 B
T5	28.7 A	1.05 A	0.070 A	22.15 A	0.59 A	0.03 B
F	9.22**	0.91 NS	0.14NS	1.13NS	14.09**	5.20**
Standard Deviation	2.92	0.18	0.012	4.4	0.147	0.007
Standard Error	0.75	0.04	0.003	1.13	0.03	0.002
CV	10.9	17.58	17.12	20.23	29.06	20.4

*Means followed by the same letter in the column do not differ from each other according to the Scott--Knott test. NS: not significant; significant at 5%; significant at 1%. Source: Prepared by the authors.

Table 2 - Values obtained from the analysis of variance and means of the treatments performed on corn seeds for the variables above-ground length (CPA), fresh above-ground mass (MFPA), dry above-ground mass (DSAP), root length (RL), fresh root mass (FRM), and dry root mass (DRM) in the laboratory trial.

Vieira et al. (2019), who reported incompatibility of *A. amazonense* with agrochemicals. This variability among species highlights the importance of evaluating different strains before recommending their use in the field. *Bacillus* sp. also exhibited growth, corroborating studies that highlight its high compatibility with fungicides and herbicides, possibly due to the production of secondary metabolites such as surfactin and proteases (Constantinescu et al., n.d.; Broccolo, 2025).

On the other hand, *Pseudomonas* sp. showed susceptibility, in agreement with Cassán and Diaz-Zorita (2016), who report limitations in the compatibility of this bacterium with fungicides. The same occurred with *Trichoderma* sp. and *Paecilomyces lilacinus*, whose results confirm reports by Loureiro et al. (2020) and Dias Neto (2014) regarding the inhibition of growth of these fungi in the presence of carboxanilides and dithiocarbamates.

These results reinforce that not all combinations of biologicals and chemicals are viable, making it essential to conduct preliminary tests to ensure the efficiency of inoculants in the field.

In Gerbox-type chamber trials, treatments T3 (*Bacillus* sp.) and T5 (*Pseudomonas* sp.) exhibited the highest mean leaf length values (28.55 cm and 28.76 cm, respectively), significantly outperforming the other treatments. Treatment T1 (*Paecilomyces lilacinus*) showed intermediate performance (26.13 cm), while the control (ST) obtained the lowest value (23.90 cm). The other variables (fresh weight, dry matter, and root length) did not show significant differences.

The higher leaf length values in the treatments with *Bacillus* sp. and *Pseudomonas* sp. suggest a greater capacity of these microorganisms to promote plant growth, possibly through the production of phytohormones, nutrient solubilization, and the induction of systemic resistance. Studies by Chagas Junior et al. (2021) confirm the potential of *Bacillus* sp. to increase the height, root length, and dry weight of soybean plants. Similarly, Godinho et al. (2019) demonstrated that *Bacillus* strains isolated from the Caatinga have the ability to produce exopolysaccharides, siderophores, and biofilms, as well as fix nitrogen—characteristics associated with promoting growth and tolerance to abiotic stresses.

These results indicate that *Bacillus* sp. and *Pseudomonas* sp. have greater potential for integration into agricultural systems, even in environments with chemical residues, while *P. lilacinus* showed intermediate performance and the control group demonstrated lower efficiency. This variability reinforces the importance of selecting appropriate microorganisms for use in conjunction with pesticides, aiming for efficiency in sustainable practices.

In the case of *Pseudomonas* sp., studies such as those by Santoyo et al. (2016) and Mendes (2025) indicate that species such as *P. fluorescens* act in the rhizosphere through the production of siderophores, organic acids, and phytohormones, which stimulate root growth and improve nutrient absorption. These mechanisms promote the development of the aboveground parts and increase plant resilience to adverse conditions, such as the presence of herbicides in the soil.

The results obtained in this study reinforce that the microorganisms used in treatments T3 (*Bacillus* sp.) and T5 (*Pseu-*

domonas sp.) possess physiological and biochemical mechanisms capable of contributing to plant growth, even in substrates previously treated with herbicides. The association between these microorganisms and the superior performance observed in the leaf length variable highlights the potential for the integrated use of biological agents in agricultural systems with a history of pesticide application.

This finding is particularly relevant for intensive production systems, in which the continuous use of herbicides can compromise the soil microbiota. The ability of *Bacillus* sp. and *Pseudomonas* sp. to maintain positive performance even under chemical stress suggests that these microorganisms can be incorporated into integrated management programs, contributing to greater sustainability and efficiency in the use of agricultural inputs.

These results demonstrate that *Bacillus sp.* and *Pseudomonas sp.* have a greater capacity to promote the growth of the above-ground parts of plants, even in substrates previously treated with herbicides. Such performance may be associated with the production of phytohormones, siderophores, and organic acids—mechanisms already described in the literature as fundamental for stimulating leaf and root development under conditions of chemical stress. The superiority of these treatments reinforces the potential for the integrated use of growth-promoting microorganisms in agricultural systems, contributing to greater physiological efficiency of plants and sustainability in seed management.

The mean values of fresh weight (FW) and dry weight (DW) of the leaves and roots of corn plants subjected to different treatments. It was observed that treatments T3 (*Bacillus* sp.) and T5 (*Pseudomonas* sp.) maintained the highest FM and DM values in the aboveground parts, reinforcing their efficacy as plant growth-promoting microorganisms. This performance suggests that both contribute to greater biomass accumulation, possibly due to the production of phytohormones, the solubilization of nutrients, and the induction of systemic resistance—mechanisms already reported in the literature as determinants of initial plant vigor.

In the root system, treatment T5 (*Pseudomonas sp.*) stood out with the highest fresh mass (0.591 g), indicating better root system development compared to the other treatments. This result may be associated with the ability of *Pseudomonas* species to produce siderophores and organic acids, which favor nutrient absorption and stimulate root growth. Furthermore, greater root biomass contributes to increased soil exploration, enhanced water and nutrient uptake, and greater plant resilience to adverse conditions, such as the presence of herbicide residues.

The results obtained in this study for MF and MS regarding leaf length indicate that *Bacillus* sp. and *Pseudomonas* sp. have potential for integration into agricultural systems. The superiority of these microorganisms in promoting the growth of both the aboveground and root systems highlights their relevance as biological alternatives for sustainable management.

CONCLUSION

The present study demonstrated that in *in vitro* trials, *Azospirillum* sp. and *Bacillus* sp. exhibited tolerance to the tested fungicides and herbicides, while *Pseudomo-*

nas sp., *Trichoderma* sp., and *Paecilomyces lilacinus* showed sensitivity, with reduced or absent growth.

In Gerbox-type chamber trials, it was observed that treatments with *Bacillus sp.* (T3) and *Pseudomonas sp.* (T5) promoted greater leaf length and better initial performance of maize plants, significantly outperforming the control and the treatment with *Paecilomyces lilacinus* (T1).

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