Research Article

Effect of Phosphorus and Calcium Application via Drench on the Development of Banana Plantlets (*Musa paradisiaca*)

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Abstract | The cultivation of banana (*Musa paradisiaca*) faces challenges in nutritional management that affect its development. This study evaluated the effect of phosphorus and calcium application via drench on the growth of banana suckers. Different treatments with (i.e., Golden Calcio®, Nutriphos®) and without biostimulants were used are as follows: T1: Golden Calcio® (4 L ha^{-1}), with 13% nitrogen and 26% calcium; T2: Nutriphos® (3 L ha^{-1}), with 8% nitrogen and 30% phosphorus; and T3: Control, which received traditional soil fertilization with a mix of nitrogen, phosphorus, and potassium (N-P-K), under a randomized complete block design with 10 replications. Experiments were conducted at Finca Patricia 1, located at km 2.9 of the La Esperanza-Valencia road, Ecuador. The variables that were considered in this investigation were as follows: Plant growth, pseudostem thickening, leaf emission, and root development. The results showed that bio-stimulants, particularly Golden Calcio® and Nutriphos®, promoted greater growth and pseudostem thickening in banana suckers compared to the control group. Notable differences in plant growth and pseudostem thickening were observed with Golden Calcio®; and was found to be the most prominent treatment. Additionally, Golden Calcio® proved to be particularly effective in leaf emission and root development in banana suckers. These findings demonstrated that the application of bio-stimulants offers a substantial advantage over traditional fertilization and significantly influences the development and performance of banana plants.

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Introduction

The cultivation of banana (*Musa paradisiaca*) is not only a vital component of the global diet but also plays a crucial role in the global economy. With millions of tons produced annually, bananas have become one of the most significant and widely grown crops across various regions worldwide (Nyombi,

2020). Although commonly referred to as a tree, the banana is actually an herbaceous plant that can grow up to 15 meters in height (Brown *et al.*, 2017). There are nearly 1,000 varieties of bananas, subdivided into 50 groups, cultivated in more than 150 countries, producing around 105 million tons of banana fruit per year (Nyombi, 2020).

In this context, it is essential to consider a critical stage in the banana life cycle: The development of suckers (Ntamwira *et al.*, 2017). Suckers, or shoots, are lateral sprouts that emerge from the base of the mother plant and represent a crucial form of propagation. Their healthy development is fundamental to ensuring the continuity of the crop (Brown *et al.*, 2017). The effectiveness of agricultural practices during this initial phase can have a significant impact on the overall yield of the crop and, consequently, on the economic sustainability of farmers (Olivares *et al.*, 2022).

In this regard, early-stage nutrition is crucial for the establishment and optimal growth of banana suckers. Two essential elements at this stage are calcium and phosphorus (Johnson *et al.*, 2024). These macronutrients are not only vital for cell growth and structural development in plants, but they also play a key role in activating enzymes and metabolic processes necessary for the healthy development of seedlings (Khan *et al.*, 2023). The quality of bio-stimulants used during the initial development of suckers can make a significant difference in terms of vigor, disease resistance, and the final yield of mature plants (Johnson *et al.*, 2024). Among the various methods of applying bio-stimulants, the drench technique stands out as an efficient strategy for delivering nutrients directly to the roots, optimizing their absorption and utilization (Halpern *et al.*, 2015).

Therefore, the precise and balanced application of calcium and phosphorus using the drench technique presents a promising strategy to optimize the development of banana suckers from the early stages of growth (Leonel *et al.*, 2020). Despite the theoretical importance of this practice, empirical evidence on the effectiveness of calcium and phosphorus drenches in sucker development is limited. Systematic evaluation of these bio-stimulants under controlled conditions will confirm their potential benefits and establish guidelines for their implementation in cultivation practices.

Materials and Methods

The research was conducted at the Patricia 1 farm, located at kilometer 2.9 on the La Esperanza-Valencia Road, Ecuador, with geographic coordinates of 0°58'12.1" South latitude and 79°23'29.9" West longitude, at an altitude of 97 meters above sea level. The banana plantation, of the Williams variety, is 15 years old.

Before establishing the experiment, a thorough soil analysis was conducted in each of the plots, considering the variations in soil types present in the plantation. The experimental site has a humid tropical climate, with an average annual temperature of 24.8°C, an annual precipitation of 1988.2 mm, and an average relative humidity of 85%. The annual heliophany is approximately 898.66 hours of sunlight per year. The soil in the area has a loamy-clay texture, with a pH of 6.2 and regular topography.

The management of the plantation follows conventional agronomic practices consistent with the standards established on the farm due to its commercial nature. This includes applying traditional agronomic management techniques widely used in the banana industry. For this study, a differentiated strategy was implemented in the fertilization treatment of the banana suckers. A bio-stimulation technique via drench was used, consisting of the localized application of bio-stimulants in the root zone of the plants.

Experimental design

Three treatments (i.e. T1, T2 and T3) were investigated (Figure 1), each with a specific characteristic: T1 (Golden Calcio® with 13% nitrogen and 26% calcium, applied at a dose of 4 L ha^{-1}), T2 (Nutriphos® 8-30-0 with 8% nitrogen and 30% phosphorus, applied at a dose of 3 L ha^{-1}), and T3 (control with traditional soil fertilization using a nitrogen, phosphorus, and potassium mixture, N-P-K). The experimental design was carried out using a randomized complete block design (RCBD) with three treatments and ten replicates. Each experimental unit consisted of five banana suckers with true leaves.

Golden Calcio® is a highly soluble liquid fertilizer containing 13% of nitrate nitrogen (NO_3-N) and 26% of calcium oxide (CaO) w/v, chelated with EDTA. This proportion allows for rapid availability and

absorption of calcium by plants, and improves plant development, especially during critical stages such as flowering and fruiting. Golden Calcio® is effective in foliar, soil, or fertigation applications, reducing calcium deficiency and improving fruit quality. This fertilizer also prevents precipitation in mixtures and is compatible with other agrochemicals, representing an efficient tool for optimizing productivity in demanding agricultural systems.

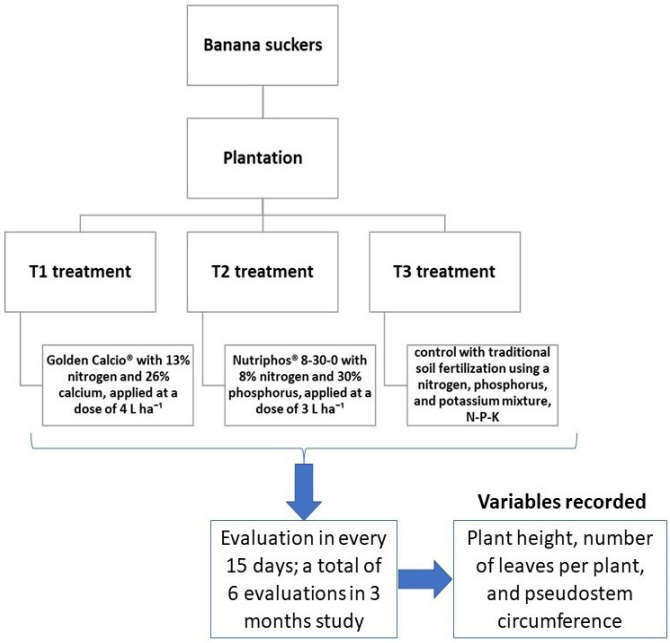

Figure 1: *Experimental design of the investigation.*

Nutriphos® (Nutriphos 8-30-0) is a highly soluble liquid fertilizer with 8% of ammonium nitrogen (NH_4-N) and 30% of P_2O_5 in the form of ammonium polyphosphate, and free of heavy metals. Its polyphosphate Equationtion reduces phosphorus fixation, improves its mobility in soils with high clay or low moisture content, and promotes synergistic absorption of NH_4^+ nitrogen. It can be applied to the soil (drench), through fertigation, or by foliar application. Its low salt content minimizes the risk of phytotoxicity and represents an efficient solution for supplying phosphorus in demanding agricultural systems.

Despite following a conventional approach in the overall management of the plantation, a significant distinction was introduced in the fertilization treatment aimed at the banana suckers. A bio-stimulation strategy via drench was implemented, consisting of the localized application of bio-stimulants in the root zone of the plants. This strategy was designed to evaluate the effects of bio-stimulation, particularly the application of phosphorus and calcium, on the development of banana suckers.

Evaluated variables

The investigation was conducted over a period of three months, allowing for the comparison of the viability of bio-stimulation via drench against three applications of conventional soil fertilization. During this period, the variables recorded were plant height, number of leaves per plant, and pseudostem circumference, every 15 days. Therefore, there were a total of 6 evaluations (i.e. 1, 2, 3, 4, 5 and 6) in a 3-months period of investigation.

For plant height, a tape measure was used to measure from ground level to the V formed by the last emitted leaves, and the average was subsequently calculated according to each evaluated treatment. The number of leaves per plant were counted for each plant in each experimental unit, and the average was determined according to the treatment under the studied conditions. The pseudostem circumference was measured one meter above ground level using a tape measure graduated in centimeters, and the average was established for each treatment under evaluation. The sucker growth (Equation 1) followed the methodology used elsewhere (Sora and Jibat Guji, 2023), considering the height of the sucker both in the first and last evaluation. Leaf emission (Equation 2) was represented by the number of leaves emitted between the first and last evaluation of the number of leaves per plant in the trial, following the methodology applied by Torres-Bazurto *et al.* (2019). The thickening of the pseudostem (Equation 3) was established by subtracting the pseudostem circumference in the last evaluation from the first evaluation, following the methodology applied by (Abdullah *et al.*, 2014).

For the weight of live, semi-live, and dead roots, an initial and final sampling of the roots extracted in a trench was conducted at 15 cm from the base of the corm, with dimensions of 30 cm wide, 15 cm long, and 30 cm deep (V = 13,500 cm^3 = 13.5 dm^3). Subsequently, the roots were washed with running water and classified as live, semi-live, and dead, weighing them using a balance to express the magnitude in grams (Stevens *et al.*, 2020), considering live roots as those that show functionality, semi-live roots as those that still provide support to the sucker, and dead roots as non-functional roots.

Sucker Height Increment (SHI) was calculated using the following Equation 1:

$$SHI = AFR - AIR$$

Where; AIR is the initial sucker height (cm); AFR is the final sucker height (cm).

The Number of Leaves Emitted (NLE) was calculated using the following Equation 2:

$$NLE = HFR - HIR$$

Where; HIR is the initial number of leaves; HFR is the final number of leaves.

The Pseudostem Circumference Increment (PCI) was determined using the following Equation 3:

$$PCI = CFR - CIR$$

Where; CIR is the initial circumference (cm); CFR is the final circumference (cm).

Statistical analysis

The data obtained from the evaluation of response variables were subjected to the Shapiro-Wilk normality test. Data analysis was performed using an Analysis of Variance (ANOVA) to determine the significance of the observed differences between treatments. Subsequently, a comparison between treatment means was conducted using Tukey's test with a significance level of 0.05 ($p \leq 0.05$). Data tabulation was done using Excel 2019, developed by Microsoft Corporation®. The statistical analysis was carried out using the Infostat software, version 2020.1.2, developed by Di Rienzo *et al.* (2008).

Results and Discussion

The analysis of variance indicated that during the first three evaluations, no significant differences in plant height were observed between treatments (Figure 2), with coefficients of variation ranging from 6.42% to 11.61% and average heights ranging from 186.20 to 241.30 cm. However, from the fourth evaluation onwards, Golden Calcio® (13% Nitrogen and 26% Calcium) showed significantly greater heights (263.50 to 300.60 cm) than Nutriphos® treatment (8% Nitrogen and 30% Phosphorus). Nonetheless, both treatments outperformed the control group with traditional N-P-K fertilization. Regarding sucker growth (Figure 3), Golden Calcio® showed the greatest increase (105.60 cm), with a significant difference compared to the control group (i.e. 73.90 cm), while Nutriphos® exhibited intermediate growth (i.e. 84.00 cm). These results demonstrated that the bio-stimulants Golden Calcio® and Nutriphos® more effectively promoted the development and expansion of banana plants compared to the control group (Khan *et al.*, 2023).

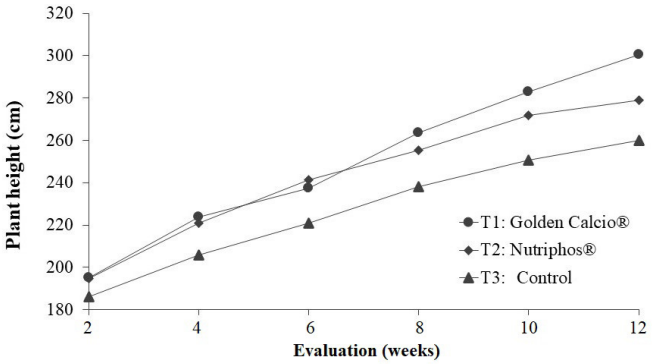

Figure 2: *Sucker height of banana plants during six biweekly evaluations in response to the application of bio-stimulants via drench.*

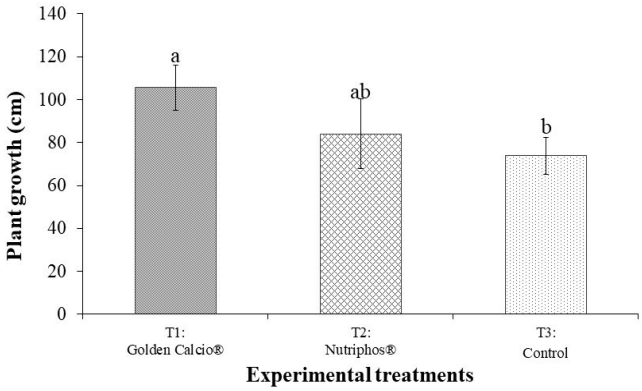

Figure 3: *Sucker growth of banana plants during six biweekly evaluations in response to the application of bio-stimulants via drench.*

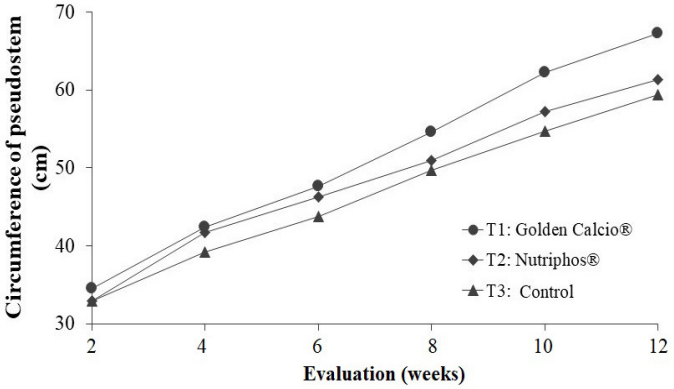

Figure 4: *Pseudostem circumference of banana suckers during six biweekly evaluations in response to the application of bio-stimulants via drench.*

From the first to the fifth evaluation, no significant differences were observed in pseudostem circumference among the different treatments (Figure 4). However, in the sixth evaluation, a 95% statistical significance was reached, with coefficients of variation ranging from 10.11% to 21.17%. In this evaluation, the Golden Calcio® treatment showed the largest circumference with 67.30 cm, significantly surpassing the control group (with a circumference value of 59.40 cm), although there were no statistical differences compared to Nutriphos® (i.e. 61.40 cm). In contrast, the analysis of pseudostem thickness (Figure 5) did not reveal significant differences among treatments, with values ranging from 26.50 to 32.80 cm and a coefficient of variation of 25.54%. These results suggested that while Golden Calcio® promoted greater pseudostem circumference, its impact on thickness was less pronounced compared to other treatments (Abdullah *et al.*, Year).

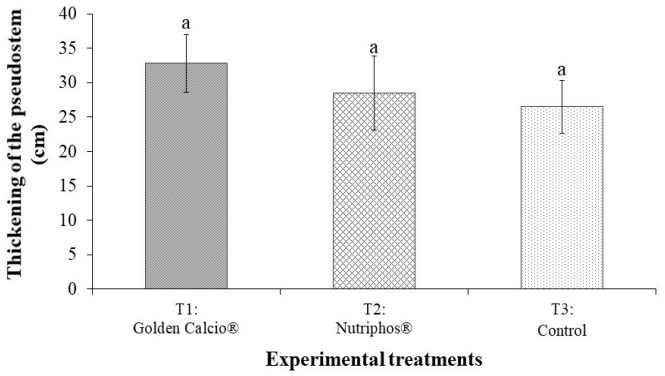

Figure 5: *Pseudostem thickening of banana suckers after six biweekly evaluations in response to the application of bio-stimulants via drench.*

Therefore, starting with the fourth evolution, Golden Calcio® promoted growth, resulting in taller plants, followed by Nutriphos®, while the control showed shorter plants. The disparity intensified in the final evaluations, confirming the effectiveness of both products in promoting vertical development.

Treatments with GoldenCalcio® (13% N, 26% Ca; 4Lha^{-1}) achieved greater pseudostem circumference and root weight, with more abundant live roots, while treatment with Nutriphos® (8% N, 30% P; 3Lha^{-1}) also improved these parameters, although to a lesser extent. In contrast, the control treatment without biostimulants showed limited development in comparison.

Regarding the number of leaves per plant (Figure 6), the analysis of variance did not reveal significant differences between treatments in any of the six evaluations performed, with coefficients of variation ranging from 11.00% to 25.48%. The average number of leaves per plant in 1 to 6 evaluations were in the range of 5.24-5.62, 7.85-8.46, 9.33-10.14, 11.08-11.78, 12.88-13.84, and 14.13-15.82, respectively. Despite this consistency, a gradual increase in the number of leaves was observed across all plants throughout the study, indicating healthy and consistent growth (Torres-Bazurto *et al.*, 2019).

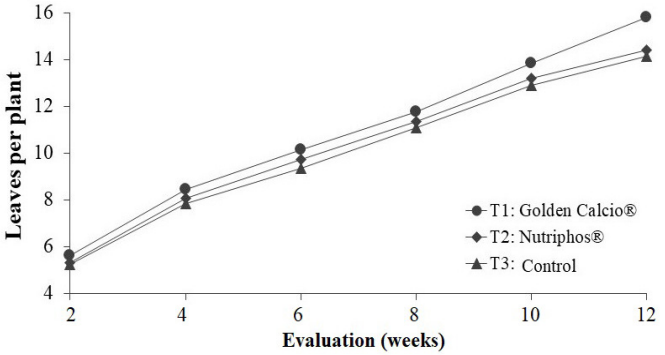

Figure 6: *Number of leaves per banana sucker during 5 weeks following the application of bio-stimulants via drench.*

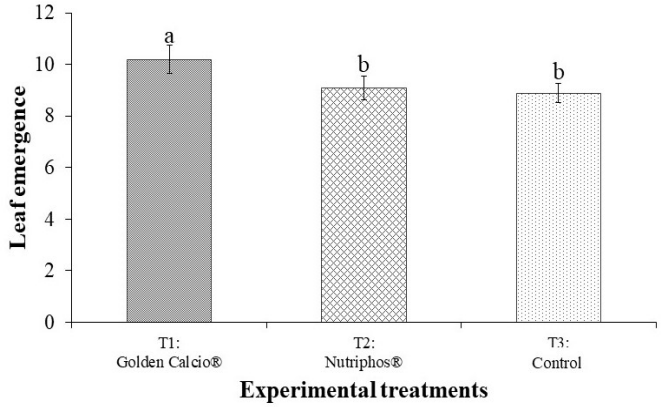

Figure 7: *Leaf emission of banana suckers after 5 weeks in response to the application of bio-stimulants via drench.*

On the other hand, regarding leaf emergence (Figure 7), treatments showed high statistical significance with a coefficient of variation of 7.85%. Golden Calcio® (T1) stood out by producing an average of 10.20 leaves per plant, significantly higher compared to Nutriphos® (T2) which had an average of 9.10 leaves, and the control group (T3) with 8.89 leaves per plant. This difference became more pronounced towards the final evaluation, highlighting the efficacy of Golden Calcio® in promoting the growth of new leaves (Nayyer *et al.*, 2014).

Although the total number of leaves per plant did not show significant differences between treatments throughout the study, the positive impact of Golden Calcio® on new leaf emission suggests that this treatment provides nutrients and bio-stimulatory compounds that enhance the production of photosynthetic leaves, which could improve the performance of the treated plants (Halpern *et al.*, 2015). Although Nutriphos® also showed beneficial effects, its impact was less pronounced compared to Golden Calcio®.

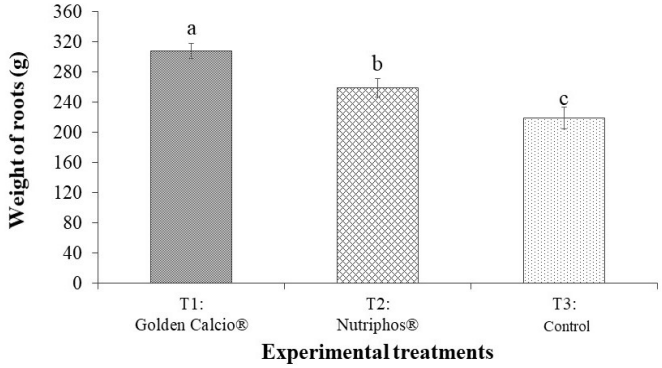

Figure 8: *Total root weight of banana suckers after 5 weeks in response to the application of bio-stimulants via drench.*

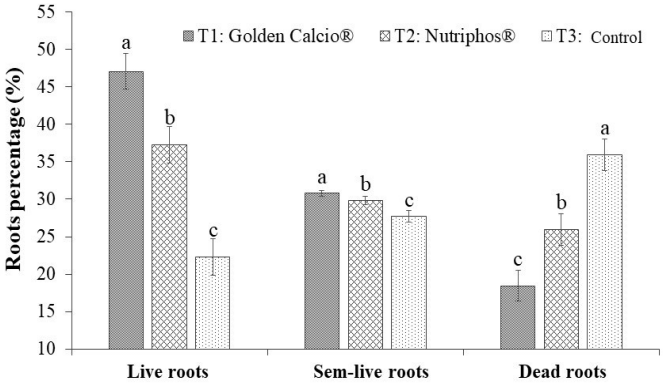

Figure 9: *Percentage of live, semi-live, and dead roots of banana suckers after 5 weeks in response to the application of bio-stimulants via drench.*

Regarding the total root weight (Figure 8), the analysis of variance revealed high statistical significance, with a coefficient of variation of 5.91%. The Golden Calcio® treatment (T1) showed the highest root weight, with an average of 307.80 g, significantly surpassing Nutriphos® (T2; 259.3 g) and the control group (T3; 219.3 g). This trend correlates with the percentages of live, semi-live, and dead roots (Figure 9), where statistical significance was also observed with coefficients of variation ranging from 1.23% to 6.42%.

Golden Calcio® exhibited the highest percentage of live and semi-live roots, with averages of 47.07% and 30.78%, respectively, outperforming Nutriphos® and the control group, which had 22.30% to 37.26% of live roots and 27.72% to 29.81% of semi-live roots. In contrast, the control group showed the highest percentage of dead roots, with 49.98%, compared to the lower percentages observed in Golden Calcio® (22.15%) and Nutriphos® (32.94%). These results highlighted the effectiveness of Golden Calcio® in promoting a healthier and more developed root system, which could positively impact the growth and productivity of banana plants (Oyeyinka and Afolayan, 2019). Although Nutriphos® also showed benefits, its effect was less pronounced compared to Golden Calcio®, underscoring the importance of nutrients and bio-stimulant compounds in root development (Ntamwira *et al.*, 2017).

Conclusion

The bio-stimulation under study did not have a significant effect on the height of banana suckers during the first three evaluations. Similarly, no significant effect was observed on the pseudostem circumference during the first five evaluations. However, in subsequent evaluations, Golden Calcio® treatment (T1) promoted greater plant height and pseudostem circumference, with a growth of 105.60 cm and a pseudostem thickness of 32.80 cm. The number of leaves per sucker was similar across all evaluations. However, when assessing leaf emission, a significant effect was observed due to the application of Golden Calcio® treatment (T1), which promoted the emission of 10.20 leaves during the study period. The roots showed greater development when Golden Calcio® was applied, with a total of 307.8 g of roots in a 1 dm^3 soil sample, of which 47.07% were live, 30.78% semi-live, and 22.15% were dead roots, significantly differing from the values recorded for other evaluated treatments, i.e. Golden Calcio® (T2 treatment) and control (T3 treatment).

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Novelty Statement

The quantitative analysis showed that the Golden Calcio® product had a significant impact on banana growth, promoting greater height, pseudostem thickening and leaf emission. In addition, it stimulated root development, with roots per dm^3 of soil, standing out as an innovative solution to improve crop yield and health in advanced stages.

Author's Contribution

Marcos Raúl Heredia-Pinos: Supervision, methodology, investigation, writing original article.
Jonathan Bismar López-Bósquez and Rubén Darío Rivera-Fernandez: Investigation, writing original article.
Sesan Abiodun Aransiola: Data analysis, writing original article.
Naga Raju Maddela: Writing original article, writing review and editing.

Generative AI and AI-assisted technology statement
The authors have declared no Generative AI and AI-assisted technologies in the writing process.

Conflict of interest
The authors have declared no conflict of interest.

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