HORIZON NEXUS JOURNAL
ISSN: 3073-1275

DOSO EDITORIAL CIENTÍFICA

Evaluation of Azotobacter vinelandii as a biostimulant in the development of cowpea (Vigna unguiculata)

Yessenia Sarango-Ortega [1,*] y Viviana Sánchez-Vásquez [2].

[1] Universidad Estatal de Milagro, Milagro, Provincia del Guayas, Ecuador,091050; https://orcid.org/0000-0001-7042-0623

[2] Universidad Estatal de Milagro, Milagro, Provincia del Guayas, Ecuador,091050; https://orcid.org/0009-0006-6911-3646; vsanchezv@unemi.edu.ec

* Correspondence: yesseniabia_93@hotmail.com

Cite: Sarango-Ortega, Y., & Sánchez-Vásquez, V. (2025). Evaluation of Azotobacter vinelandii as a biostimulant in the development of cowpea (Vigna unguiculata). *Horizon Nexus Journal*, *3*(2), 90-102. https://doi.org/10.70881/hnj/v3/n2/62

Received: 10/02/2025
Revised: 20/04/2025
Accepted: 25/04/2025
Published: 30/04/2025

https://doi.org/10.70881/hnj/v3/n2/62

Abstract: The study evaluated the effect of a biostimulant based on *Azotobacter vinelandii* on the germination, development and flowering of cowpea (*Vigna unguiculata*). *A. vinelandii* is a nitrogen-fixing bacterium capable of improving plant growth. An experiment was designed with seven treatments and three repetitions, applying different doses of the biostimulant (8 g, 12 g and 24 g) in combination with drinking water (T1) and pineapple peel water (T2). Variables such as germination rate, plant height, number of leaves and flowers, length of the root system and stem thickness were analyzed. The results showed that the biostimulant had a positive impact on germination and growth, with the 24 g dose standing out as the most effective, especially in the development of the root system and leaf production. However, no significant differences were observed in the number of pods produced. It is concluded that *Azotobacter vinelandii* is a viable alternative to improve cowpea yield, contributing to a more sustainable agriculture by reducing the use of chemical fertilizers.

Keywords: Biostimulant; *Azotobacter vinelandii*; plant growth

Resumen: El estudio evaluó el efecto de un bioestimulante basado en Azotobacter vinelandii sobre la germinación, el desarrollo y la floración del caupí (Vigna unguiculata). A. vinelandii es una bacteria fijadora de nitrógeno capaz de mejorar el crecimiento de las plantas. Se diseñó un experimento con siete tratamientos y tres repeticiones, aplicando diferentes dosis del bioestimulante (8 g, 12 g y 24 g) en combinación con agua potable (T1) y agua de cáscara de piña (T2). Se analizaron variables como la tasa de germinación, la altura de la planta, el número de hojas y flores, la longitud del sistema radicular y el grosor del tallo. Los resultados mostraron que el bioestimulante tuvo un impacto positivo en la germinación y el crecimiento, destacando la dosis de 24 g como la más eficaz, especialmente en el desarrollo del sistema radicular y la producción de hojas. Sin embargo, no se observaron diferencias significativas en el número de vainas producidas. Se concluye que Azotobacter vinelandii es una alternativa viable para mejorar el rendimiento del caupí, contribuyendo a una agricultura más sostenible al reducir el uso de fertilizantes químicos.

Palabras claves: Bioestimulante; Azotobacter vinelandii; crecimiento vegetal

1. Introduction

The cowpea bean (*Vigna unguiculata*) is a legume of high nutritional value and great importance in agriculture in tropical and subtropical regions due to its tolerance to low fertility conditions (Morales, 2023). However, its production faces significant limitations, such as the restricted availability of nitrogen in the soil, low germination rates, and adverse environmental factors that compromise its development and flowering (Daconceição et al., 2022). These constraints underscore the need for sustainable strategies that optimize crop yields without relying on the intensive use of synthetic fertilizers (Higuera & Avellaneda, 2020).

Biostimulants based on beneficial microorganisms have emerged as an ecological alternative to improve agricultural productivity. *Azotobacter vinelandii*, an atmospheric nitrogen-fixing bacterium, also produces phytohormones such as auxins, cytokinins, and gibberellins, promoting plant growth (Martin del Campo et al., 2022). Its application in crops has been shown to improve nutrient absorption and increase plant biomass (Peña et al., 2015). In this context, assessing the impact of *A. vinelandii* on cowpeas could be an effective strategy for sustainably increasing its productivity.

Despite its potential benefits, the use of *A. vinelandii* in cowpeas still lacks sufficient experimental evidence. Previous research suggests that plant response to biofertilizers depends on the concentration applied and soil characteristics, which highlights the need to establish optimal doses to maximize their positive effects (W. Escobar et al., 2017). It has also been documented that different levels of biostimulants can influence different stages of plant development, which justifies specific studies for each crop and environment (Quintero et al., 2018).

The present study aims to determine the optimal concentration and type of suspension of a biostimulant based on *A. vinelandii* to improve the germination, growth, and flowering of cowpea beans (Lara et al., 2010). It is hypothesized that the application of this biostimulant in adequate doses will significantly increase morphological parameters such as plant height, number of leaves, stem thickness, and flower and pod production compared to a control group. To evaluate this hypothesis, an experiment was designed using three concentrations of the biostimulant (8 g, 12 g, and 24 g), dissolved in drinking water (T1) and pineapple peel water (T2) (Mero, 2021), The latter as a source of enzymes, organic compounds and bioactive metabolites that could favor the activity of *A. vinelandii*.

The main challenge of this research lies in the development of efficient methods to optimize cowpea bean production without resorting to the excessive use of synthetic fertilizers, whose negative environmental impact and high cost have been widely documented (Daconceição et al., 2022) The application of nitrogen-fixing microorganisms such as *A. vinelandii* represents a promising alternative to improve soil fertility and reduce dependence on chemical inputs in agriculture (Huaman, 2021).

This analysis aims to produce evidence about the effectiveness of *A. vinelandii* as a biostimulant in cowpeas, determining the ideal dose to enhance its influence on crop yield. Promoting the use of natural biofertilizers not only increases productivity in agriculture but also promotes the reduction of agrochemical use and the implementation of sustainable agriculture models (Albarracin, 2024). The results achieved could be used in the creation of more effective agronomic management strategies, favoring both small-scale producers and the preservation of the natural environment.

2. Material and Methods

The purpose of this study was to assess the impact of a biostimulant based on *A. vinelandii* on germination, development, and flowering of cowpea (*Vigna unguiculata*). To achieve this, an experiment was conducted under field conditions with different doses of the biostimulant, evaluating its influence on the morphological and physiological variables of the crop.

Study Design

The present research is framed within an experimental study, with a quantitative and explanatory approach, whose objective is to establish the causal relationship between the application of the biostimulant and the growth of cowpea beans. For this purpose, a completely randomized experimental design was adopted, in which seven different treatments were implemented, each replicated three times. The variables evaluated in the study included germination speed, plant height, stem thickness, number of leaves and flowers, root system length, as well as the number of pods produced.

The test was carried out in Milagro, Ecuador, in soil with a sandy loam texture and a climate marked by an average temperature of 25°C and a relative humidity of 80%. Black-eyed pea seeds were used. The biostimulant used was *A. vinelandii* at doses of 8g, 12g, and 24g, purchased from the Asociación de Producción Industrial Licán (ASOPROIL) mixed with drinking water (T1) and pineapple peel water (T2).

Inclusion and exclusion criteria

To ensure the uniformity of the research, specific criteria were established for the choice of biological material:

- Seeds of homogeneous size and without perceptible imperfections were chosen. The plants analyzed had to have completed their germination stage under normal conditions.
- Seeds showing signs of physical damage or disease before planting were removed. In addition, seeds that did not germinate on schedule were discarded.
- Throughout the experiment, plants with irregularities in their development or that were impacted by pests and diseases not related to the research were discarded.

Procedure

The experimental procedure involved several fundamental phases. First, the seeds were subjected to pretreatment by submerging them in solutions with different doses of biostimulant for 12 hours, and then manually sowing in plots arranged in three rows with five holes each, with a depth of 3 cm, placing two seeds in each hole. Then, solutions of the biostimulant, prepared in 8L of drinking water (T1) and pineapple peel water (T2), were used utilizing irrigation oriented to the base of the stem. Weekly applications were carried out for six weeks to ensure uniform distribution. Additionally, to verify the quality and viability of the biostimulant (*A. vinelandii*), a cell count was performed using the Neubauer chamber method and microscopic observation at 400x.

Irrigation was drip irrigated for the first 15 days and then every other day, while weed management was carried out by manual removal every 15 days and the use of garlic extract as a natural pest repellent. Finally, weekly evaluations of factors such as germination rate, plant height, leaf width, stem thickness, number of leaves and flowers, number of pods, and length of the root system were carried out.

Data analysis

The data collected were grouped in matrices and examined by ANOVA to detect relevant differences between treatments. To contrast the averages and establish which biostimulant dose showed the best performance in each variable, Tukey's multiple comparisons test was used with a significance level of 0.05. Statistical analyses were carried out using the MINITAB program.

3. Results

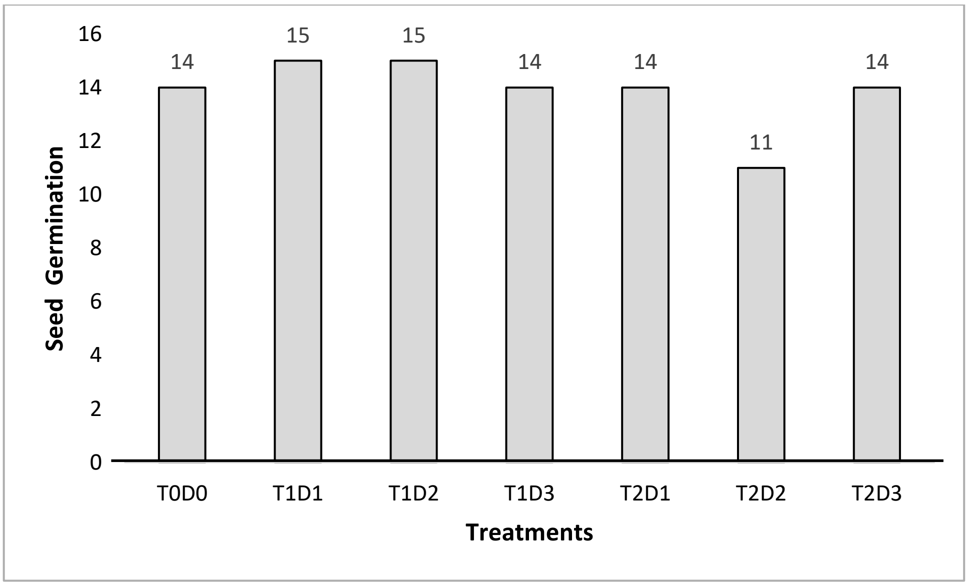
The evaluation of the findings made it possible to assess the impact of the biostimulant based on *A. vinelandii* on the germination, development, and flowering of cowpea (*Vigna unguiculata*), exposing the most significant findings concerning the variables analyzed.

Seed germination

The germination rate was generally high in most treatments, with small variations. It was observed that seeds treated with the biostimulant presented a higher germination percentage compared to the control group. In particular, the 8g (D1) and 12g (D2) doses in the T1 treatment achieved the highest number of germinated seeds (15 in total). On the other hand, the 12g (D2) dose in treatment T2 showed the lowest germination rate (11 germinated and 4 non-germinated seeds) (Figure 1).

Figure 1

Seed germination

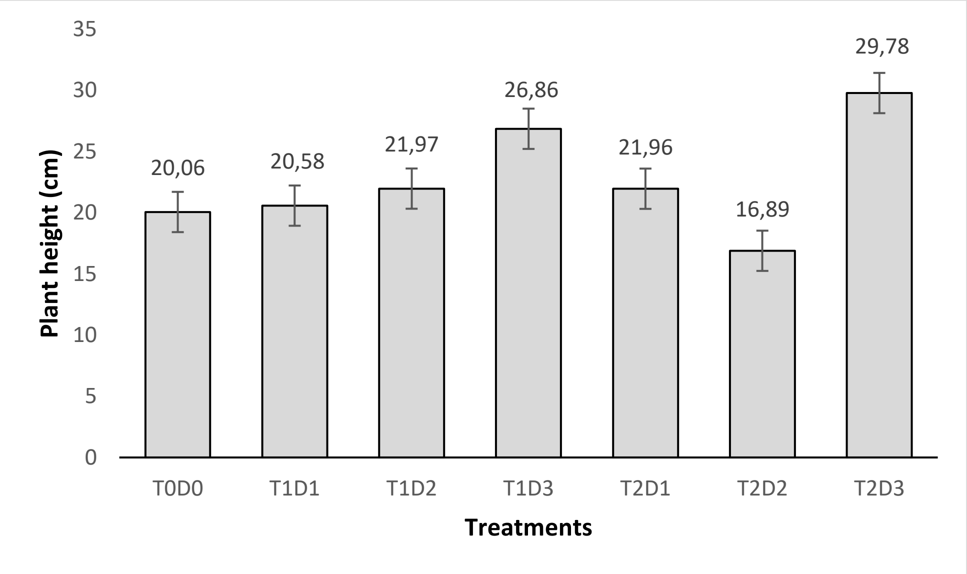


Note. Number of germinated seeds for each treatment T0D0 (Control), T1 (Treatment 1 – *A. vinelandii* + Drinking water), T2 (Treatment 2 – *A. vinelandii* + Pineapple peel water), D1 (Dose 1- 8g), D2 (Dose 2 - 12g), D3 (Dose 3 - 24g).
Source: Authors

Plant Height

Height measurements showed that the biostimulant treatments promoted the development of cowpeas, with notable differences between the doses used. The results indicate that the greatest height was obtained in the 24 g (D3) dose of treatment 2 (29.78 cm), followed by the same dose in treatment 1 (26.86 cm). In contrast, the control treatment and the 12g (D2) dose in treatment 2 recorded the smallest values (Figure 2). The analysis of variance showed significant differences between treatments (p = 0.059), with 6.46% of the variability attributable to the treatment and 41.90% to experimental error. This suggests that the biostimulant has a positive effect on plant height, although other factors also influence growth.

Figure 2
Effect of treatments on plant height.



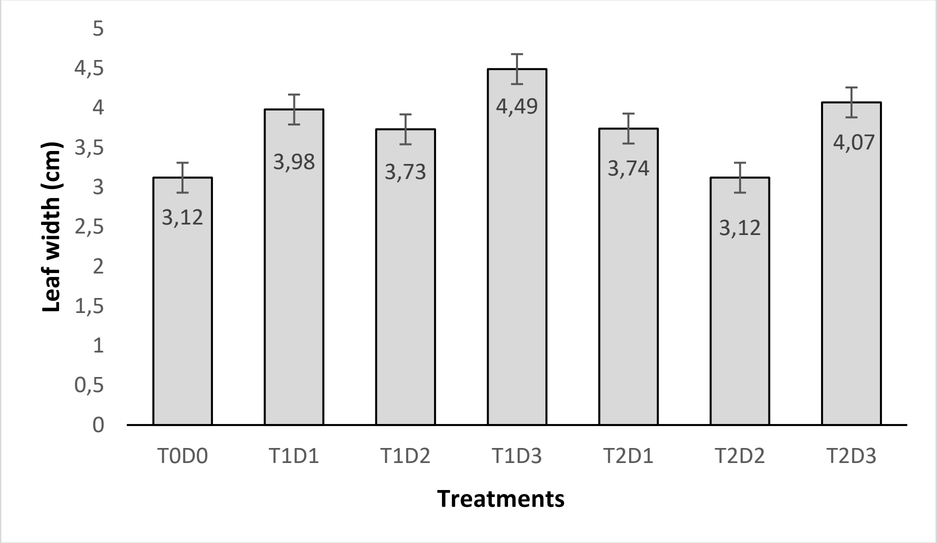
Note. Average plant height (cm) under different treatments. T0D0 (Control), T1 (Treatment 1 – *A. vinelandii* + Drinking water), T2 (Treatment 2 – *A. vinelandii* + Pineapple peel water), D1 (Dose 1- 8g), D2 (Dose 2 - 12g), D3 (Dose 3 -24g). The highest height in T2D3 (29.78 cm) and the lowest in T2D2 (16.89 cm).
Source: Authors

Leaves width

Leaves width also showed considerable variations among the different treatments. The plants that were treated with *A. vinelandii* presented wider leaves compared to the control group, highlighting the dose of 24g (D3) at T1 with an average of 4.49 cm (Figure 3). The analysis of variance revealed a marginally significant difference between treatments (p = 0.055), with 16.31% of the variability explained by the treatments. These findings indicate that the biostimulant could improve leaf structure, favoring light uptake and thus photosynthetic efficiency.

Figure 3

Variation in leaf width (cm) under different treatments



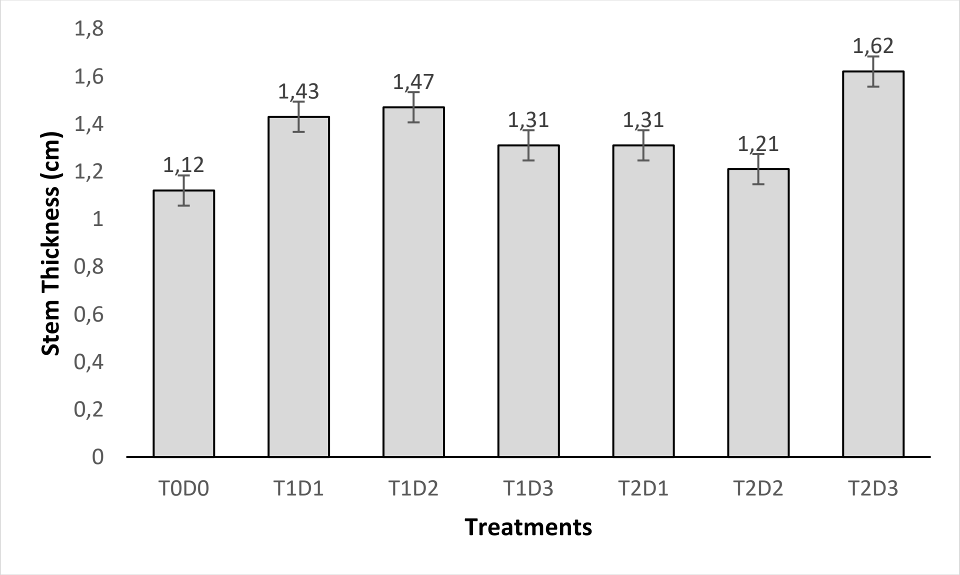
Note. Average leaf width (cm) as a function of different treatments. T0D0 (Control), T1 (Treatment 1 – *A. vinelandii* + Drinking water), T2 (Treatment 2 – *A. vinelandii* + Pineapple peel water), D1 (Dose 1- 8g), D2 (Dose 2 - 12g), D3 (Dose 3 -24g). Source: Authors

Stem size

Regarding stem size, the T2 treatment recorded the highest yield with the 24g dose (1.62 cm), followed by the T1 treatment with the 12g dose (1.47 cm), while the control group showed the lowest results (Figure 4). The analysis of variance showed a significant difference between treatments (p = 0.055), with 13.36% of the variability presented by the biostimulant. This suggests that *A. vinelandii* may contribute to stem thickening, providing greater structural support to the plant.

Figure 4

Effect of the treatments on stem thickness

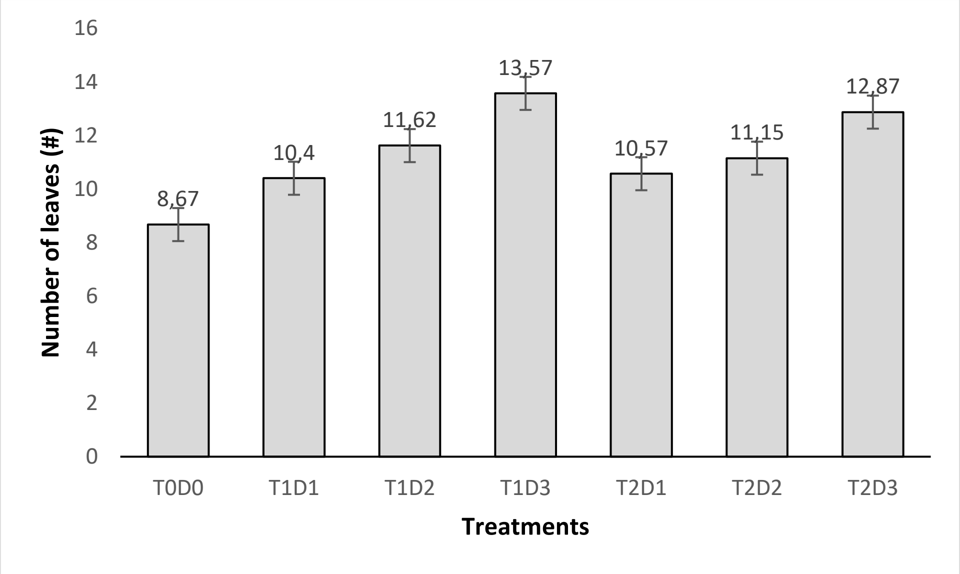


Nota. Average stem thickness (cm) in response to different treatments. T0D0 (Control), T1 (Treatment 1 – *A. vinelandii* + Drinking water), T2 (Treatment 2 – *A. vinelandii* + Pineapple peel water), D1 (Dose 1- 8g), D2 (Dose 2 - 12g), D3 (Dose 3 -24g).
Source: Authors

Leaf development and flowering

The number of leaves showed a positive response to the biostimulant, treatment T1 with dose D3 presented the highest number of leaves, with an average of 13.57 leaves per plant (Figure 5). The analysis of variance showed a significant difference between treatments (p = 0.067), with 2.56% of the variability explained by the treatments.

Figure 5
Variation in the average number of leaves under different treatments

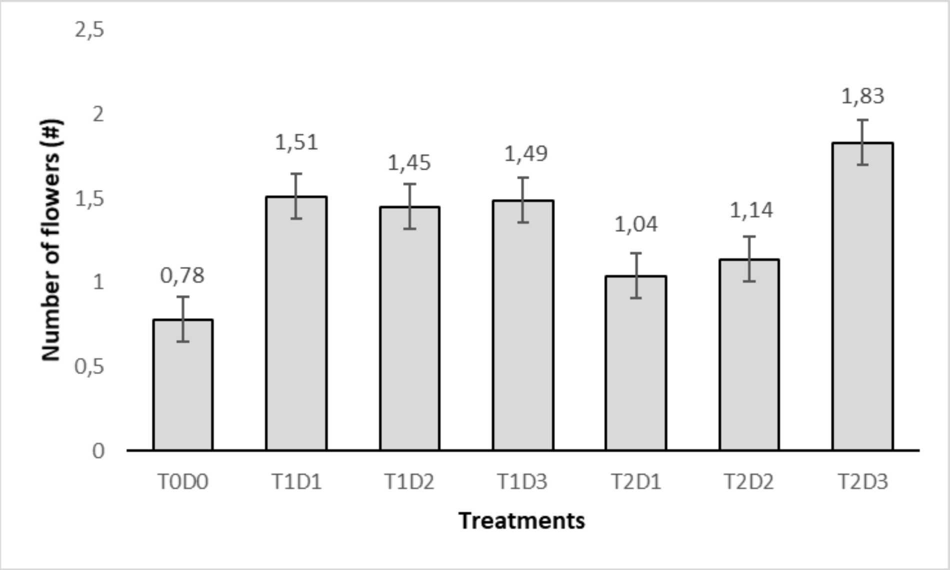


Note. The average number of leaves in plants subjected to different treatments. T0D0 (Control), T1 (Treatment 1 – *A. vinelandii* + Drinking water), T2 (Treatment 2 – *A. vinelandii* + Pineapple peel water), D1 (Dose 1- 8g), D2 (Dose 2 - 12g), D3 (Dose 3 - 24g).
Source: Authors

Concerning flowering, significant differences were observed among treatments, highlighting the 24g dose at T2, with an average of 1.83 flowers per plant, indicating that *A. vinelandii* can promote higher floral production in cowpea (Figure 6). Analysis of variance showed a marginally significant difference (p = 0.065), suggesting that the biostimulant could stimulate floral production by enhancing nutrient uptake and availability of bioactive compounds.

Figure 6

Number of flowers in response to different treatments



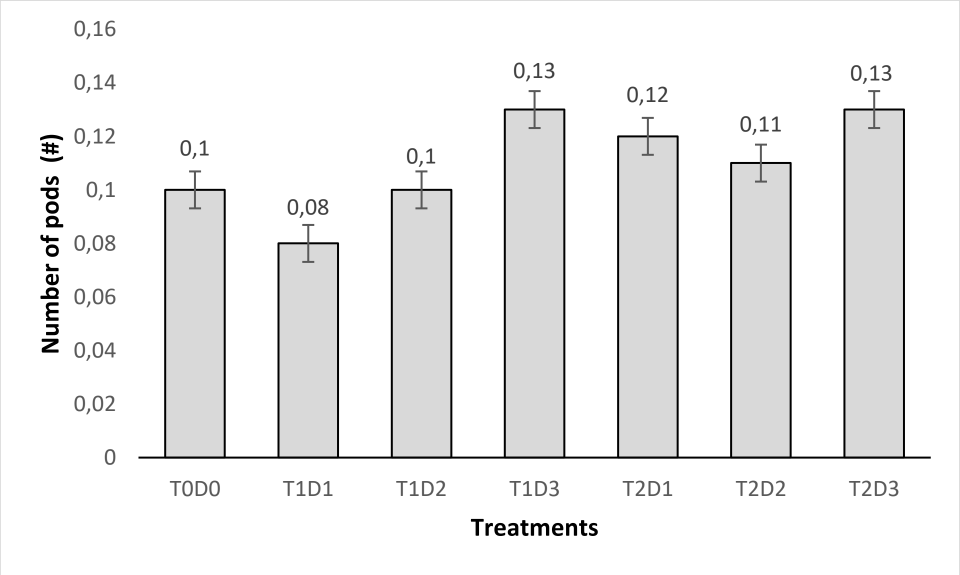
Nota. The average number of flowers in plants subjected to different treatments. T0D0 (Control), T1 (Treatment 1 – *A. vinelandii* + Drinking water), T2 (Treatment 2 – *A. vinelandii* + Pineapple peel water), D1 (Dose 1- 8g), D2 (Dose 2 - 12g), D3 (Dose 3 - 24g).
Source: Authors

Pod production and root development

In the analysis of the number of pods per plant, no significant differences were found among treatments, since all presented similar values, with a maximum average of 0.13 pods per plant in T1 and 2 in dose 3 (Figure 7).

Figure 7

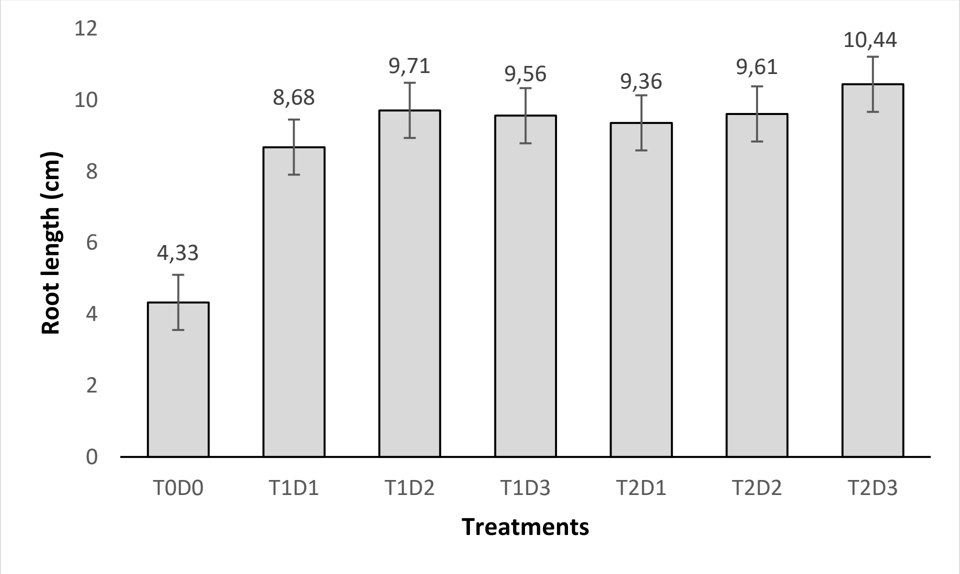
Number of pods in response to different treatments



Note. The average number of pods in plants subjected to different treatments. T0D0 (Control), T1 (Treatment 1 – *A. vinelandii* + Drinking water), T2 (Treatment 2 – *A. vinelandii* + Pineapple peel water), D1 (Dose 1- 8g), D2 (Dose 2 - 12g), D3 (Dose 3 - 24g).
Source: Authors

The root system showed a favorable response to the biostimulant, with significant differences among treatments. The greatest root length was recorded in treatment T2 with dose D3, reaching an average of 10.44 cm, followed by T1 with dose 2 (9.71 cm), while the control group presented the shortest roots (4.33 cm) (Figure 8). The analysis of variance reflected significant differences between treatments (p = 0.043), with 19.68% of the variability, these results reinforce the hypothesis that *A. vinelandii* could improve water and nutrient absorption capacity by stimulating root development.

Figure 8
Effect of treatments on the root system.



Note. Average root system length (cm) in response to different treatments. T0D0 (Control), T1 (Treatment 1 – *A. vinelandii* + Drinking water), T2 (Treatment 2 – *A. vinelandii* + Pineapple peel water), D1 (Dose 1- 8g), D2 (Dose 2 - 12g), D3 (Dose 3 -24g).
Source: Authors

4. Discussion

The results obtained support the hypothesis that this microorganism promotes plant growth by enhancing nutrient uptake and stimulating key physiological processes.

An increase in the germination of seeds treated with the biostimulant was observed in comparison with the control group, with greater effectiveness at the doses of 12g (D1) and 18g (D2) in T1. This coincides with previous studies showing that *A. vinelandii* promotes germination by producing phytohormones such as indoleacetic acid (IAA) and gibberellins, which stimulate cell elongation and early root emergence (Escobar et al., 2011). In addition, its ability to fix atmospheric nitrogen improves the availability of essential nutrients for initial plant development (Pérez et al., 2014).

However, the lower germination observed at the 12 g dose in T2 could be related to environmental factors or to the presence of metabolites in the pineapple water used in this treatment, which could affect seed viability.

In plant height, the biostimulant significantly favored the development of cowpea beans, with a greater height at the 24 g dose at T2 (29.78 cm). The literature indicates that A. vinelandii improves plant growth by producing siderophores, which facilitate iron uptake, and volatile compounds that modulate the expression of genes related to plant development (M. D. Sánchez, 2017).

Likewise, a positive effect on leaf width and stem thickness was also observed, suggesting an improvement in photosynthetic capacity and structural resistance of the plant. These results are consistent with research indicating that *Azotobacter spp.* can improve leaf morphology and water use efficiency by inducing the accumulation of osmoprotectants such as proline and trehalose (Pedraza et al., 2018). Although the differences are significant, the variability in some treatments suggests that other factors such as soil nutrient availability or interaction with native microorganisms may influence growth.

The application of the biostimulant had an impact on flowering, with a higher number of flowers at the 24 g dose at T2 (1.83 flowers/plant). This suggests that *A. vinelandii* stimulates the synthesis of phytohormones involved in flowering, such as cytokinins and ethylene at low concentrations (Velasco et al., 2020). However, no significant differences were found in pod production between treatments, indicating that the conversion of flowers to fruit may depend on other factors such as pollination and climatic conditions (Quintero et al., 2018).

Previous studies report that legume yield response to biostimulants is highly variable and depends on the interaction with soil microbiota and macronutrient availability (Escobar et al., 2011) Therefore, it is possible that the positive effect of the biostimulant on flowering may not translate into a higher number of pods due to competition for resources at later stages of development.

The most pronounced effect of the biostimulant is observed in the root system, with a greater root length at the 24 g dose at T2 (10.44 cm). This reinforces the hypothesis that *A. vinelandii* enhances nutrient and water uptake by stimulating root growth through the production of growth regulators and phosphate solubilization (Ariza et al., 2020).

These findings coincide with research on other legumes, where it has been shown that plant growth-promoting bacteria can increase root biomass by up to 30%, improving the efficiency of water and nutrient uptake, which is crucial in soils with low fertility (Santoyo et al., 2023).

This analysis provides evidence of the benefit of *A. vinelandii* on cowpea development, highlighting its capacity as a sustainable biofertilizer in the agricultural sector. However, further studies are needed to enhance its effectiveness. Specifically, it is crucial to analyze its interaction with the soil microbiota, since its performance is based on coexistence and rivalry with indigenous microorganisms (J. M. Sánchez et al., 2022). It is also advisable to examine other agronomic elements, such as fertilization and pollination, since these can affect the final performance of the crop (Pérez-Pazos & Sanchez-Lopez, 2017). Although an increase in flowering is noted, pod production does not show notable variations, indicating the importance of investigating the underlying processes that influence the transformation of flowers into viable reproductive structures.

5. Conclusions

This research demonstrates the capacity of *A. vinelandii* as a biostimulant in cowpea production, prevailing its role in increasing plant growth through sustainable biological processes. Its ability to capture atmospheric nitrogen and generate phytohormones makes it a feasible option compared to artificial fertilizers, with direct advantages in agricultural productivity and the reduction of the environmental effect linked to the use of agrochemicals.

One of the most relevant contributions of this research is the identification of a positive effect of the biostimulant on the growth and development parameters of cowpeas, which supports the importance of exploring beneficial microorganisms as allies in sustainable agriculture. In addition, the findings suggest that the formulation and the medium in which *A. vinelandii* is applied may influence its effectiveness, opening the door to future research on the optimization of its use in different crops and soil and climatic conditions.

The promotion of root growth observed in this research is an indication that *A. vinelandii* could improve the efficiency of nutrient and water uptake, which would be key in the adaptation of crops to environmental stress conditions. From an applied perspective, the results reinforce the need to promote agricultural practices that integrate beneficial microorganisms as biotechnological tools accessible to small and medium-sized producers.

Therefore, this study establishes a basis for future research focused on the interaction of *A. vinelandii* with the soil microbiota, its persistence in diverse agricultural systems, and its influence on final crop production. The importance of understanding more deeply the variables that control the transformation of flowers into viable reproductive structures, together with the impact of the biostimulant on final yield, generates new possibilities for refining its use in modern agriculture.

Contributions author: conceptualization, YB-SO. and VLSV.; methodology, YB-SO.; software, YB-SO.; validation, YB-SO.; formal analysis, YB-SO.; research, YB-SO. and VLSV.; resources, YB-SO. and VLSV.; writing the original draft, YB-SO.; drafting, revising and editing, YB-SO.; visualization, YB-SO.; supervision, YB-SO. All authors have read and accepted the published version of the manuscript.

Funding: This research has not received external funding.

Acknowledgments: We thank all those who collaborated in the conduct of this study, providing technical and academic support. Their contribution was essential for the development of this research.

Data availability statement: Data are available upon request to the authors of correspondence: yesseniabia_93@hotmail.com

Conflict of interest: The authors declare that they have no conflict of interest.

References

Albarracin, F. A. (2024). Análisis de abonos orgánicos y químicos. *Revista Teinnova*, *8*, 52–59. https://doi.org/10.23850/25007211.6356

Ariza, S., González, O., & López, J. (2020). Evaluación de fijadores biológicos de nitrógeno libres sobre el crecimiento de gramíneas en suelo degradado. *Revista Colombiana de Biotecnología*, *22*(0123–3475), 87–97. https://doi.org/10.15446/rev.colomb.biote.v22n1.78019

Daconceição, L. F., Ruiz Sánchez, E., & Jimenez Osornio, J. J. (2022). Caracterización agro-morfológica de 20 cultivares de frijol caupí (*Vigna unguiculata* [L.] Walp.) en Yucatán, México. *Acta Universitaria*, *32*. https://doi.org/10.15174/au.2022.3216

Escobar, C., Horna, Y., Carreño, C., & Mendoza, G. (2011). Caracterización de cepas nativas de Azotobacter spp. y su efecto en el desarrollo de Lycopersicon esculentum Mill. “tomate” en Lambayeque. *Scientia Agropecuaria*, *2(1)*, 39–49. https://www.redalyc.org/articulo.oa?id=357633697005

Escobar, W., Tafur-Recalde, V., Pazmiño, J., & Ramiro J. Vivas-Vivas. (2017). Respuesta del cultivo de fréjol caraota (Phaseolus vulgaris L.) a la aplicación foliar complementaria de tres bioestimulantes. *Dominio de las Ciencias*, *3*, 556–571. https://doi.org/http://dx.doi.org/10.23857/dom.cien.pocaip.2017.3.3.jun.556-571

Higuera, L. C., & Avellaneda, L. M. (2020). Estrategias para el fortalecimiento de la sostenibilidad ambiental (con enfoque agropecuario) y la seguridad alimentaria de la vereda Huerta Grande del municipio de Boyacá. *Revista Luna Azul*, *50*, 84–106. https://doi.org/10.17151/luaz.2020.50.5

Huaman, E. (2021). *Influencia del nitrógeno y fósforo en el comportamiento agronómico del frijol caupí (Vigna unguiculata L. Walp) en Cieneguillo Centro-Sullana-2019*. https://ediciones.inca.edu.cu

Peña, K., Rodríguez, J. C., & Santana, M. (2015). Comportamiento productivo del frijol (Phaseolus vulgaris L.) ante la aplicación de un promotor del crecimiento activado molecularmente. *Revist Cientific Avances*, *17*(1562–3297), 327–337. https://dialnet.unirioja.es/servlet/articulo?codigo=5350926

Lara, C., Pahola, L., & Oviedo, L. E. (2010). Medio de cultivo utilizando residuos-sólidos para crecimiento de bacteria nativa con potencial biofertilizante. *Rev. Colomb. Biotecnol*, *12(1)*, 103–112. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0123-34752010000100011

Martin del Campo, J. S., Rigsbee, J., Bueno Batista, M., Mus, F., Rubio, L. M., Einsle, O., Peters, J. W., Dixon, R., Dean, D. R., & Dos Santos, P. C. (2022). Overview of physiological, biochemical, and regulatory aspects of nitrogen fixation in *Azotobacter vinelandii*. In *Critical Reviews in Biochemistry and Molecular Biology* (Vol. 57, Issues 5–6, pp. 492–538). Taylor and Francis Ltd. https://doi.org/10.1080/10409238.2023.2181309

Mero, L. (2021). *Efecto de Azotobacter en la producción de maní (Arachis hypogaea) cantón Milagro, parroquia Mariscal Sucre* [UNIVERSIDAD AGRARIA DEL ECUADOR

FACULTAD DE CIENCIAS AGRARIAS]. https://cia.uagraria.edu.ec/Archivos/MERO%20DAVID%20LADY%20JOHANNA.pdf

Morales, F. (2023). *Cultivo de caupí: diversificación para la resiliencia agrícola* (1). https://www.cimmyt.org/es/noticias/cultivo-de-caupi-diversificacion-para-la-resiliencia-agricola/

Pedraza, R. O., Estrada Bonilla. German Andres, & Bonilla Buitrago, R. R. (2018). *Los biofertilizantes y su relación con la sostenibilidad agrícola*. http://hdl.handle.net/20.500.12324/36977

Pérez, F., Alías, C., Bellogín, R. A., Del Cerro, P., Espuny, M. R., Jiménez, I., López-Baena, F. J., Ollero, F. J., & Cubo, T. (2014). Plant growth promotion in cereal and leguminous agricultural important plants: From microorganism capacities to crop production. In *Microbiological Research* (Vol. 169, Issues 5–6, pp. 325–336). Urban und Fischer Verlag Jena. https://doi.org/10.1016/j.micres.2013.09.011

Pérez-Pazos, J. V., & Sanchez-Lopez, D. B. (2017). Caracterización y efecto de Azotobacter, Azospirillum y Pseudomonas asociadas a ipomoea batatas del Caribe Colombiano. *Revista Colombiana de Biotecnologia*, *19*(0123–3475), 39–50. https://doi.org/10.15446/rev.colomb.biote.v19n2.69471

Quintero, E., Calero, A., Pérez, Y., & Enríquez, L. (2018). Effect of different biostimulants in the yields of common beans Revista Centro Agrícola. *Revista Centro Agricola*, *45*(0253–5785), 73–80. http://cagricola.uclv.edu.cu

Sánchez, M. D. (2017). *Producción de sideróforos por cepas de Azotobacter spp. aisladas de suelos de cultivos hortícolas del Altiplano Cundiboyacense* [Pontificia Universidad Javeriana]. http://hdl.handle.net/10554/57907

Sánchez, J. M., Velázquez-Medina, A., Cabrera-Reinaldo, I., Amador-Vargas, W. L., & Vela-Muzquiz, G. R. (2022). Supervivencia de Azotobacter y otros grupos microbianos en suelo seco almacenado . *Journal of the Selva Andina Research Society*, *13*(1), 3–15. https://doi.org/10.36610/j.jsars.2022.130100003

Santoyo, F., Khalil-Gardezi Abdul, Carrillo-Castañeda Guillermo, Ortega-Escobar Héctor Manuel, Mancilla-Villa Oscar Raúl, Rubiños-Panta Juan Enrique, López-Buenfil José Abel, Larque-Saavedra Mario Ulises, Haro-Aguilar Gabriel, & Ali-Gamboa Cristian Alejandro. (2023). Efecto de bacterias promotoras del crecimiento vegetal (Medicago sativa L.) en dos tipos de suelo, cobre y composta. *Acta Universitaria*, *1(33)*, 1–14. /https://doi.org/10.15174/au.2023.3569

Velasco, A., Castellanos, O., Acevedo, G., Aarland, R. C., & Rodríguez, A. (2020). Rhizospheric bacteria with potential benefits in agriculture. *Terra Latinoamericana*, *38*(2), 343–355. https://doi.org/10.28940/terra.v38i2.470