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The effect of *Bacillus* spp. and vermicompost on the growth of cherry tomato, *Solanum lycopersicum* L., fruits

El efecto de *Bacillus* spp. y el humus de lombriz sobre el crecimiento de frutos de tomate cherry, *Solanum lycopersicum* L.

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ABSTRACT

In this investigation, we evaluate the effect of Bacillus spp. and vermicompost on the growth of cherry tomato, *Solanum lycopersicum* L., fruits. We used four treatments: T1. Vermicompost (112 g). T2. Vermicompost (112 g) in combination with the consortium of bacteria of the genus *Bacillus* (*B. subtilis, B. thuringiensis var. kurstaki, B. pumilus, and B. amyloliquefaciens*) at a concentration of $1x10^8$ colony forming units (CFU)/mL and in a dosasge of 3 mL/L of water. T3. The consortium of bacteria of the genus *Bacillus* at the concentration and dose mentioned and, T4. Control (untreated soil). Our experimental design was in the completely randomized design with three replications. We used the tomato fruit's weight, horizontal diameter, and vertical diameter as variable responses. Significant differences between treatments were assessed with one-way analysis of variance (ANOVA) and classified with Tukey's honestly significant difference (HSD) test. The assumptions of normality, homogeneity of variations, and data independence were verified. The Wilcoxon test was used to assess differences in the chemical composition of the fruits of each treatment. The results showed that the highest values of average fruit weight, 15.21 g and 12.99 g, were statistically equivalent obtained with T2 and T3; correspondingly compared to 11.86 g obtained in the control. There were no statistical differences between treatments in the vertical and horizontal diameter. It is concluded that the application of vermicompost in combination with the *Bacillus* consortium (T2); or individually (T3), significantly increases fruit weight and improves the nutritional value (N, P, K, Ca, S, Mg, Fe, Mn, Cu, Zn, B, and Na).

Keywords: bacteria; *B. amyloliquefaciens*; *B. pumilus*; *B. subtilis*; *B. thuringiensis*; nutrient content.

RESUMEN

En este trabajo se evaluó el efecto de *Bacillus spp*. y vermicompost en el crecimiento de frutos de tomate cherry, *Solanum lycopersicum* L. Se utilizó cuatro tratamientos: T1. Vermicompost (112 g). T2. Vermicompost (112 g) en combinación con el consorcio de bacterias del género *Bacillus* (*B. subtilis, B. thuringiensis var. kurstaki, B. pumilus y B. amyloliquefaciens*) a una concentración de $1x10^8$ unidades formadoras de colonias (UFC)/mL y en una dosis de 3 mL/L de agua. T3. El consorcio de bacterias del género *Bacillus* a la concentración y dosis mencionadas y, T4. Control (suelo sin tratamiento). El diseño experimental fue completamente al azar con tres réplicas. Se utilizaron como variables respuesta el peso, diámetro horizontal y diámetro vertical del fruto. Las diferencias significativas entre tratamientos se evaluaron con análisis de varianza de una vía (ANOVA) y se clasificaron con la prueba de diferencia honestamente significativa (HSD) de Tukey. Se verificaron los supuestos de normalidad, homogeneidad de variaciones e independencia de los datos. Se utilizó la prueba de Wilcoxon para evaluar las diferencias en la composición química de los frutos de cada tratamiento. Los resultados mostraron que los valores más altos de peso promedio de fruto, 15,21 g y 12,99 g, fueron estadísticamente equivalentes obtenidos con los T2 y T3; comparados con 11,86 g en el control. No hubo diferencias entre tratamientos con relación al diámetro vertical y horizontal. Se concluyó que la aplicación de vermicompost en combinación con el consorcio *Bacillus* (T2); o de forma individual (T3), incrementa significativamente el peso del fruto y mejora el valor nutricional (N, P, K, Ca, S, Mg, Fe, Mn, Cu, Zn, B y Na).

Palabras Clave: bacteria; *B. amyloliquefaciens*; *B. pumilus*; *B. subtilis*; *B. thuringiensis*; contenido nutricional.

INTRODUCTION

The cherry tomato (*Solanum lycopersicum* L.) has its origins in Central and South American countries, though some reports attribute it to Mexico, and it has now spread to all five continents (Peralta *et al.,* 2006; Knapp & Peralta, 2016; FAOSTAT, 2020). Its antioxidant properties, such as vitamin C, carotenoids, flavonoids, and phenols, along with its sensory appearance, taste, quality, and exquisite aroma, have facilitated its rapid acceptance in markets. It is commonly used for fresh consumption or in salads (Leyva *et al.,* 2014; Liu *et al*., 2018; Sinha & Purcell, 2019; García-Alonso *et al.*, 2020; Guo *et al*., 2021; FAO, 2021).

In 2022, tomatoes became the second most-produced vegetable globally, with 186,107,972 tons produced over 4,917,735 hectares, yielding 37.84 tons per hectare (FAOSTAT, 2024). In that same year, the top five countries in tomato production were China, India, Turkey, the United States, and Egypt. In Colombia, tomato production reached 875,436 tons, making it the second most significant crop after onions (FAOSTAT, 2024).

In 2019, global pesticide use reached 4,196,533 tons, representing an increase of 27,755 tons (0.67%) compared to the previous year (4,168,778 tons) (FAOSTAT, 2019). Many Latin American countries have banned pesticides containing highly toxic ingredients, such as chlordane, DDT, endosulfan, hexachlorobenzene, aldicarb, captafol, carbofuran, and monocrotophos, due to their harmful effects on air, soil, water, plants, and animals (Pesticideinfo, 2022).

In Colombia, despite banning 34 harmful pesticides—such as alachlor, aldicarb, carbofuran, and endosulfan—the country consumed 69,862 tons of pesticides in 2019, ranking tenth worldwide (FAOSTAT, 2019; Pesticideinfo, 2022). These bans are based on inadequate usage practices, such as lack of personal protective equipment, the exceeding of recommended doses, the improper disposal of plastic waste without sufficient washing, the leakage of ingredients at storage sites, and the release of waste into soil and water sources, among others.

Additionally, these pesticides have been associated with diseases such as cancer and Parkinson's disease, autism spectrum disorders, and acute human poisoning through the consumption of contaminated food. Chronic environmental exposure has also been linked to ecological degradation and long-term toxicity (Cremlyn, 1990; Iizuka *et al.,* 2013; del Puerto Rodríguez *et al.,* 2014; PAN 2021; Guo *et al*., 2021).

In Colombia, tomato production is generally carried out through conventional agriculture, which has enabled mass, stable food production. However, the high frequency of pesticide usage has led to high residual concentrations such as pyrimethanil, carbendazim, dimethomorph, and acephate in the fruit (Arias *et al.,* 2014). In some cases, these concentrations have exceeded the maximum residue limits permitted, such as carbendazim (0.74 $mg \cdot kg^{-1}$) and thiocyclam in fruits (0.79 $mg \cdot kg^{-1}$), indoxacarb in leaves (24.81 $mg \cdot kg^{-1}$), and dimethomorph in soils (44.45 $mg \cdot kg^{-1}$) (Arias *et al*., 2014; Pérez-Consuegra, 2018; Arias *et al.*, 2021). It is important to maintain food safety standards, a priority for public health, and an essential step to achieving food security while complying with the maximum levels set by the Codex Alimentarius (Iizuka *et al.,* 2013; Saidi *et al.,* 2017). The use of natural compounds and alternative substances is another possible solution to reduce the entrance of pesticides into the food chain and environment (Bakhtiarizade & Souri, 2019; Ebrahimi *et al*., 2021a, b).

The production of many crops, including tomatoes, largely depends on the application of chemical fertilizers, the main being nitrogen fertilizers in the form of nitrates (NO_3^-) and ammonium (NH_4^+) (Souri *et al.*, 2009; Souri, 2010). Many N forms are more readily soluble in water, meaning their effects on the plant are seen in a short space of time due to the high concentration of available nitrogen (Qahraman *et al.,* 2020; Kai *et al.*, 2020; Guo *et al.*, 2021). Furthermore, the use of inorganic fertilizers combined with eutrophication can create a nutrient imbalance that restricts the uptake of other essential nutrients and causes soil acidity, reducing crop productivity (Ojeniyi, 2000; Sharma, 2017; Kumar Bhatt *et al.*, 2019; Nosheen, 2021). For example, in Guangdong, China, it has been reported that the application of 100% nitrogen, phosphorus, and potassium (NPK) inorganic fertilizers increased the tomato yield by 72.9%; however, soil quality deteriorated significantly as a result (Wu *et al.*, 2022).

In nature, a significant portion of nutrients exists in forms unavailable to plants. Thus, the use of microorganisms presents an alternative to nutrient solubilization (Rawat *et al.*, 2018). Clean production offers an alternative to conventional agriculture, which helps to reduce the need to rely on artificial phytosanitary inputs, create environmentally friendly agronomic practices, produce low-contaminant foods, and ensure high levels of soil biodiversity and quality. (Mącik *et al*., 2020). Within clean production systems, the cultivation of vegetables with organic amendments has gained global traction due to the minimal environmental pollution it causes and the satisfactory outcomes it has produced. Therefore, the concept of efficiently recycling organic waste from agricultural activities using organic fertilizers has been revitalized, aiming to minimize the indispensable use of synthetic fertilizers for plant nutrition (Truong *et al*., 2018).

One of the organic fertilizers providing significant nutrient absorption and retention capacity is vermicompost, characterized by a finer structure and larger surface area compared to other fertilizers (Truong *et al*., 2018; De Matos *et al*., 2021). According to reports from the University of Campina Grande in Brazil, using vermicompost (2 L per plot) as fertilizer for tomato cultivation resulted in fruits with a longitudinal diameter of 21.3 mm, surpassing the diameter of tomatoes treated with NPK chemical fertilizer by 0.9 mm and exceeding the control treatment by 3.3 mm. Similarly, the tomato yield with vermicompost was 0.045 kg higher compared to the control plants. It is concluded that vermicompost fertilization can fully replace chemical fertilization under similar conditions without compromising yield or fruit quality (De Matos *et al*., 2021). Furthermore, a study conducted at the National Pingtung University of Science and Technology in Taiwan found that a substrate mix of vermicompost, rice husk ash, and coconut fiber increased the substrate pH from 4.7 to 6.5. Additionally, both the tomato plants and fruits thrived and developed favorably in this substrate mix (Truong et al., 2018).

In the past few decades, significant progress has been made in the production and utilization of biofertilizers containing bacteria from genera like *Rhizobium*, *Pseudomonas*, *Bacillus*, *Klebsiella*, *Azotobacter*, and *Azospirillum*. These bacteria, known as plant growth-promoting rhizobacteria (PGPR), can: colonize roots; enhance soil structure and fertility; improve tolerance to biotic and abiotic stress; facilitate nutrient uptake; ensure optimal crop yield; and reduce the dependency on agrochemicals (Murray-Núñez *et al.*, 2011; Pathania *et al.*, 2020; Kour *et al.*, 2020; Zainuddin *et al.*, 2022).

One of the globally recognized PGPRs is *Bacillus subtilis*, known for its ability to fix nitrogen and solubilize phosphates through enzymes like nitrogenases and phytases (Corrales Ramírez *et al.*, 2017). It is also notable for its ability to enhance the productivity potential of various crops (Corrales Ramírez *et al*., 2017; Shafi *et al.,* 2017). Chowdappa *et al*. (2013) discovered that applying *B*. *subtilis* to tomato seeds resulted in an average root growth of 14.9 cm, which was higher than the 10.6 cm observed in control plants. Similarly, the leaf area of seedlings increased by 3.1 cm^2 compared to control seedlings with a leaf area of 3.4 cm^2. Furthermore, it is noted that by inoculating *B*. *subtilis* on tomato seedlings at planting and re-inoculating the bacteria twice after planting (20 days apart), the incidence of gray mold disease (*Botrytis cinerea*) was reduced by 84%.

Given the above, the present research aims to evaluate the effect of the combination of PGPR bacteria *Bacillus subtilis*, *Bacillus thuringiensis* var. kurstaki, *Bacillus pumilus*, and *Bacillus amyloliquefaciens*, as well as vermicompost, individually or in combination, on the growth and development of cherry tomato fruits.

MATERIAL AND METHODS

The research was conducted from August 2022 to March 2023 in the Vanegas village of the Sogamoso municipality, Boyacá, with coordinates of 5°42′57″ N, 72°56′00″ W and an altitude of 2,569 meters. The average temperature was 17°C, and the relative humidity was 76%. The soil's chemical characteristics were as follows: pH of 6.05; high content of B (0.52 $mg \cdot kg^{-1}$), Ca (9.27 $cmol \cdot kg^{-1}$), K (0.86 $cmol \cdot kg^{-1}$), Fe (337.11 $mg \cdot kg^{-1}$), Mn (15.31 $mg \cdot kg^{-1}$), and Zn (10.77 $mg \cdot kg^{-1}$). The soil had an electrical conductivity (EC) of 0.45 dS m-1, free of salts, and a medium organic matter content (5.26 g per 100 g^{-1}, organic carbon 3.05), P (26.10 $mg \cdot kg^{-1}$), S (12.04 $mg \cdot kg^{-1}$), Cation Exchange Capacity (12.69 $cmol \cdot g^{-1}$), Mg (2.49 $cmol \cdot kg^{-1}$), Cu (2.26 $mg \cdot kg^{-1}$), Na (<0.14 $cmol \cdot kg^{-1}$), and Al and K saturation percentages were within normal parameters.

The soil in the plots was prepared using a hoe and disinfected with a 3% hydrogen peroxide solution sprayed directly onto the soil using a sprayer. After one week, furrows were created, each measuring 9.80 m in length, 0.60 m in width, and 0.40 m in depth, with a spacing of 0.80 m between furrows. The seedlings were germinated from seeds in a substrate consisting of enriched soil, peat, humus, and vermiculite (25:40:25:10), and they were initially grown in a germination tray.

On August 27, 2022, cherry tomato seedlings were transplanted in the furrows. These seedlings had an average height of 7 cm with four true leaves and were 30 days old. The seedlings were planted at a depth of 5 cm and spaced 50 cm apart, with a total area of 7.73 m in width by 9.86 m in length.

Experimental design. A completely randomized block design was established with four treatments (including the control) and three replications. The evaluated treatments were as follows: 1. Vermicompost (112 g). 2. Vermicompost (112 g) in combination with a mixture of *Bacillus* genus bacteria, including *B. subtilis*, *B. thuringiensis* var. kurstaki, *B. pumilus*, and *B. amyloliquefaciens*, each at a concentration of $1x10^8$ colony forming units per milliliter CFU mL^{-1} (3 $cm^3 \cdot L^{-1}$). 3. A mixture of *Bacillus* genus bacteria including *B. subtilis*, *B. thuringiensis* var. kurstaki, *B. pumilus*, and *B. amyloliquefaciens*, each at a concentration of $1x10^8$ CFU mL^{-1} (3 $cm^3 \cdot L^{-1}$). 4. Control (untreated soil). The vermicompost dosage for treatments 1 and 2 was based on soil analysis, while the bacterial mixture dosage followed the recommendations in the product's technical data sheet. The treatments were applied directly to the soil around the root zone of each plant, at the time of sowing and after sowing, with a frequency of 15 days until the flowering period.

Throughout the crop cycle, manual weeding was performed every 15 days. Additionally, foliar applications were carried out once a week using a rechargeable sprayer, with extracts of chili pepper (*Capsicum pubescens*) and garlic (*Allium sativum*) in a ratio of 2:1. Furthermore, a neem oil solution (*Azadirachta indica*) was applied directly to the soil at the base of each plant. The neem oil solution was prepared at a dosage of 3 cm^3 per liter of water. This application aimed to control pests such as the African land snail (*Lissachatina fulica*), cutworms (*Agrotis ipsilon*), and beetles (*Diabrotica barberi*).

Evaluated variables. The harvest was conducted from January 10th to March 12th, 2023, when the tomatoes reached a maturity index of 5 according to the Castro *et al*. (2009) scale. A total of 23 samples were harvested over eight weeks. For each sample, the following variables were recorded every six days:

- Weight (W) in grams (g): The fruits were weighed using digital scales accurate to 0.01 g (PLU reference: 102132826) with a capacity of 500 g.
- Horizontal diameter (Hd) in millimeters (mm): Measured using a Vernier caliper, a metal ruler with a length of 6 inches (150 mm) across the width of the fruit.
- Vertical diameter (Vd) in millimeters (mm): Measured using the caliper, perpendicular to each of the harvested tomatoes (1.536).
- Representative samples of the fruits from each treatment were also taken and sent to the AGRILAB® laboratory for conventional analysis of the plant material.

Statistical Analysis. A one-way analysis of variance (ANOVA) was conducted to identify the presence of statistical differences among the treatments, and Tukey's honestly significant difference (HSD) test at a 95% confidence level was performed to determine the grouping of means and their differentiation (Lagos-Burbano & Criollo-Escobar, 2019; Legarda *et al*., 2001). Analyses were conducted and assumptions were verified using coding routines in the statistical software R version 4.3.0 (R Core Team, 2023). Residual normality, homogeneity of variances, and data independence were assessed using the Shapiro-Wilk, Bartlett, and Durbin-Watson tests, respectively (Lawal, 2014). Non-parametric Wilcoxon tests were used to evaluate differences in the chemical composition of the fruits, as the data did not follow a normal distribution (Ramachandran & Tsokos, 2021).

RESULTS AND DISCUSSION

The ANOVA detected statistical differences ($p < 0.1$) in fruit weight among treatments. Subsequently, Tukey's HSD test revealed the formation of three groups: treatments 2 and 3 exhibited statistical equivalence ($p < 0.1$) and were superior to treatments 1 and 4. Treatments 1 and 4 showed statistical differences between each other (Table 1). In contrast, no statistical differences were found for the vertical and horizontal diameter variables among treatments. However, treatment 2 yielded the highest mean values and the greatest percentage differences for all three evaluated variables (Table 2); for example, the fruit weight of treatment 2 showed an increase of 28.37% compared to treatment 4, while concerning treatment 1, the increase in this variable was 19.1%.

On the other hand, the absence of statistical differences in the horizontal and vertical diameter variables is because the percentage differences did not exceed 8% (Table 2).

Table 1. Analysis of Variance (ANOVA) of Tomato Fruit Weight, Horizontal Diameter, and Vertical Diameter.

Treatment	Weight (g) ± Standard deviation	Horizontal diameter (mm) ± Standard deviation	Vertical diameter (mm) ± Standard deviation
1	$12.73^{a} \pm 0.69$	$27.28^{a} \pm 0.52$	$24.33^{a} \pm 0.54$
2	$15.21^{b} \pm 0.98$	$25.95^{a} \pm 0.76$	$23.29^{a} \pm 0.59$
3	$12.99^{b} \pm 0.92$	$25.86^{a} \pm 0.73$	$23.2^{a} \pm 0.5$
4	$11.86^{c} \pm 1.68$	$25.7^{a} \pm 1.41$	$22.63^{a} \pm 1.4$

The means with different letters are statistically different.

Table 2. Differences in the mean of treatment 2 about 1, 3, and 4.

Treatment	Weight (g)	Horizontal diameter (mm)	Vertical diameter (mm)
1	2.48 g (19.51 %)	1.34 mm (5.15 %)	1.13 mm (4.88 %)
3	2.23 g (17.14 %)	1.43 mm (5.52 %)	1.7 mm (7.52 %)
4	3.36 g (28.37 %)	1.59 mm (6.2 %)	1.04 mm (4.45 %)

The effect of *Bacillus* spp. on weight has been reported in various studies; for example, Uysal & Kantar (2020) found that in field conditions, inoculating potato tubers (*Solanum tuberosum* L.) with the mixture of *Bacillus subtilis* and *Bacillus amyloliquefaciens* (concentration of $1x10^9$ UFC mL^{-1}) presented a difference of 6.47g when compared to the control (68.89g). Likewise, Shafi *et al*. (2017) found that applying spore suspensions of the OTB1 strain of *Bacillus* spp. to tomato seeds led to vigorous growth and development in the seedlings. Similarly, Hussain & Hasnain (2015) found that when inoculating cucumber cotyledons (*Cucumis sativus* L.) with *Bacillus licheniformis*, there was a difference of 31.55g in comparison to the control (water), which was larger by 2.04g with *Bacillus subtilis*.

In this research, treatment 1 (12.73 g) presented a difference of 1.27 g in fruit weight compared to the control, which weighed 11.54 g. This difference was greater than that reported by Márquez-Hernández et al. (2006) in greenhouse-grown cherry tomatoes. In their study, the application of 13 kg of worm humus to a substrate composed of 53 kg of sand and perlite resulted in a difference of 0.2 g in fruit weight compared to the control, which reached a weight of 11.2 g. The combined application of *Bacillus* spp. and worm humus not only increases the weight of plant organs but also provides nutrients to the crop and promotes ecosystem preservation (Velasco Sánchez *et al.,* 2017).

On the other hand, the horizontal and vertical diameters exhibited statistical equality with p-values of 0.3 and 0.19, respectively (Table 1). This can be attributed to the lower percentage difference between the treatment means (Table 2). However, highly significant correlations ($p < 0.01$) were observed, with a correlation coefficient of 0.86 between the horizontal and vertical diameters and correlation coefficients of 0.94 and 0.87 between the weight and the horizontal and vertical diameters, respectively.

Regarding the horizontal and vertical diameters, treatment 2 exhibited greater differences in means (1.98 cm and 4.44 cm) compared to the control (25.46 cm and 23 cm) in the given order (Table 1). The difference observed in the horizontal diameter exceeded that reported by Zulueta *et al*. (2020), which was 0.05 about the control (23 cm) when *Bacillus subtilis* was inoculated in hybrid Caporal tomato fruits. It has been observed that the increase in weight, diameter, and organ development in plants may be linked to the stimulation of cytokinin production caused by *Bacillus spp*., which plays a role in cell division and plant development (Amara *et al*., 2015).

In general, the values of the variables obtained in this research exhibited a decreasing trend throughout the harvest period; the average weight of the fruits from sample 1 was 18 g, and that of sample 20 reached 9 g (Figure 1). However, the decreasing trend in the weight, horizontal diameter, and vertical diameter of the fruits from the first harvest (January 10, 2023) to the last one (March 12, 2023) (Figure 1) is associated with severe frost occurring 15 days after the first harvest, during which 100% of the flowers dropped to the ground. Although 70% of the formed fruits were preserved, 30%

also fell. Following these losses due to extreme temperature conditions, a reduction in the values of the mentioned variables was observed. As reported by Raza *et al.* (2021), freezing stress can lead to partial or complete fruit loss and plant damage due to the formation of intercellular ice that causes cell and tissue injuries. Similarly, Thakur *et al.* (2010) mention that extremely cold temperatures result in yield losses due to interference with sexual reproduction (meiosis), leading to flower abortions, infertility, and impaired fruit filling.

The results of the chemical analyses (Table 3) describe that the nutrient content of N, P, K, Ca, S, Mg, Fe, Mn, Cu, Zn, B, and Na increased with treatment 2 compared to the other treatments. This higher content of Fe, Cu, and Zn is reported to be associated with the ability of *Bacillus* spp. to produce siderophores or chelating compounds for Fe^{3+} and Zn^{2+}, which enhance the solubility and availability of micronutrients for plants (Thomine & Lanquar, 2011; Maheshwari, 2012; Wairich *et al.*, 2019).

Differences in the chemical element content in the fruits were analyzed using the non-parametric Wilcoxon test. Before analysis, the values of each parameter were standardized between 0 and 1, as shown in Table 2. Additionally, in Figure 2 and Table 4, it can be observed that treatments 1 and 4, as well as treatments 2 and 3, form two statistically distinct groups ($p < 0.01$ between groups), while being statistically similar ($p < 0.01$) within each group.

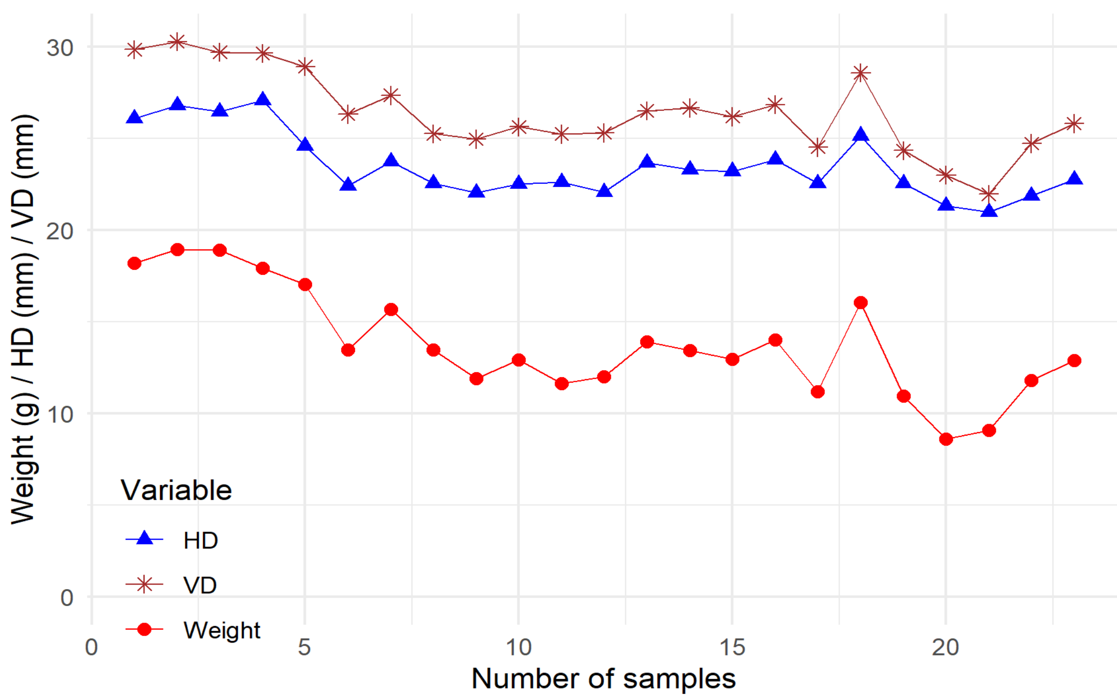

Figure 1. Behavior of the mean values of the weight, horizontal diameter, and vertical diameter of the cherry tomatoes during the harvest period (23 samples).

Similarly, the greatest variations in nutrients were observed in the Ca/B ratio (Table 3). This could be associated with the high maturity index of 5 at which the fruits were harvested, along with the close relationship between these elements in cell wall formation and fruit ripening (Bolaños *et al.*, 2004). Similarly, Bouček *et al*. (2023) reported an increase in nutrients such as P, K, Ca, Mg, and S in potted tomatoes treated with earthworm humus and *B. amyloquefaciens* compared to untreated soil. Moreover, Etesami *et al.* (2023) mention that the use of *Bacillus* spp. can enhance the availability of nutrients such as N, P, K, Fe, Mn, Cu, and Zn for plant uptake, consequently promoting plant development and growth.

Table 3. Nutrient content, saturation, and exchangeable base ratios in fruits from Vanegas, Sogamoso (Boyacá).

Variable	Expression	Unit	Treatment outcomes (standardized values)			
			1	2	3	4
Moisture	N.A.	%	90.9 (0.2477)	92.7 (0.2526)	91.0 (0.248)	92.4 (0.2518)
Nitrogen (a)	N Organic	%	2.13 (0.2396)	2.30 (0.2587)	2.36 (0.2655)	2.10 (0.2362)
Phosphorus	P	%	0.387 (0.2323)	0.433 (0.2599)	0.468 (0.2809)	0.378 (0.2269)
Potassium	K	%	3.52 (0.2383)	3.88 (0.2627)	3.95 (0.2674)	3.42 (0.2316)
Calcium	Ca	%	0.136 (0.2252)	0.176 (0.2914)	0.160 (0.2649)	0.132 (0.2185)
Magnesium	Mg	%	0.157 (0.252)	0.157 (0.252)	0.169 (0.2713)	0.140 (0.2247)
Sulfur	S	%	0.213 (0.2396)	0.232 (0.261)	0.244 (0.2745)	0.200 (0.225)
Iron	Fe	mg/kg	35.8 (0.2358)	40.1 (0.2642)	37.1 (0.2444)	38.8 (0.2556)
Manganese	Mn	mg/kg	5.90 (0.2582)	6.01 (0.263)	6.37 (0.2788)	4.57 (0.2)
Copper	Cu	mg/kg	8.43 (0.242)	10.5 (0.3015)	8.23 (0.2363)	7.67 (0.2202)
Zinc	Zn	mg/kg	16.5 (0.2416)	18.3 (0.2679)	17.9 (0.2621)	15.6 (0.2284)
Boron	B	mg/kg	11.8 (0.2495)	11.9 (0.2516)	12.6 (0.2664)	11.0 (0.2326)
Sodium	Na	mg/kg	351 (0.2623)	332 (0.2481)	369 (0.2758)	286 (0.2138)
Potassium Saturation	Sat. K	%	82.0 (0.2491)	82.1 (0.2494)	82.2 (0.2497)	82.9 (0.2518)
Calcium Saturation	Sat. Ca	%	6.18 (0.2361)	7.26 (0.2774)	6.49 (0.248)	6.24 (0.2384)

Variable	Expression	Unit	Treatment outcomes (standardized values)			
			1	2	3	4
Magnesium Saturation	Sat. Mg	%	11.8 (0.264)	10.7 (0.2394)	11.3 (0.2528)	10.9 (0.2438)
Calcium / Magnesium Ratio	Ca/Mg	Adimensional	0.525 (0.2233)	0.680 (0.2892)	0.574 (0.2442)	0.572 (0.2433)
Calcium / Potassium Ratio	Ca/K	Adimensional	0.075 (0.2358)	0.089 (0.2799)	0.079 (0.2484)	0.075 (0.2358)
Mg / K Ratio	Mg/K	Adimensional	0.143 (0.2634)	0.130 (0.2394)	0.138 (0.2541)	0.132 (0.2431)
(Calcium + Magnesium) / Potassium Ratio	(Ca+Mg)/K	(Ca+Mg)/K	0.219 (0.2541)	0.219 (0.2541)	0.217 (0.2517)	0.207 (0.2401)
Nitrogen / Sulfur Ratio	N/S	N/S	10.0 (0.2495)	9.91 (0.2473)	9.67 (0.2413)	10.5 (0.262)
Nitrogen / Phosphorus Ratio	N/P	N/P	5.50 (0.2569)	5.31 (0.248)	5.04 (0.2354)	5.56 (0.2597)
Calcium / Boron Ratio	Ca/B	Ca/B	115 (0.2255)	148 (0.2902)	127 (0.249)	120 (0.2353)
Iron / Manganese Ratio	Fe/Mn	Fe/Mn	6.07 (0.2244)	6.67 (0.2466)	5.82 (0.2152)	8.49 (0.3139)

Table 4. Comparison of treatments using the Wilcoxon test

Comparison of medians		W	p
T1	T2	119	0.000492
T1	T3	162	0.00937
T1	T4	357.5	0.152
T2	T3	339	0.293
T2	T4	491	0.0000284
T3	T4	455	0.000574

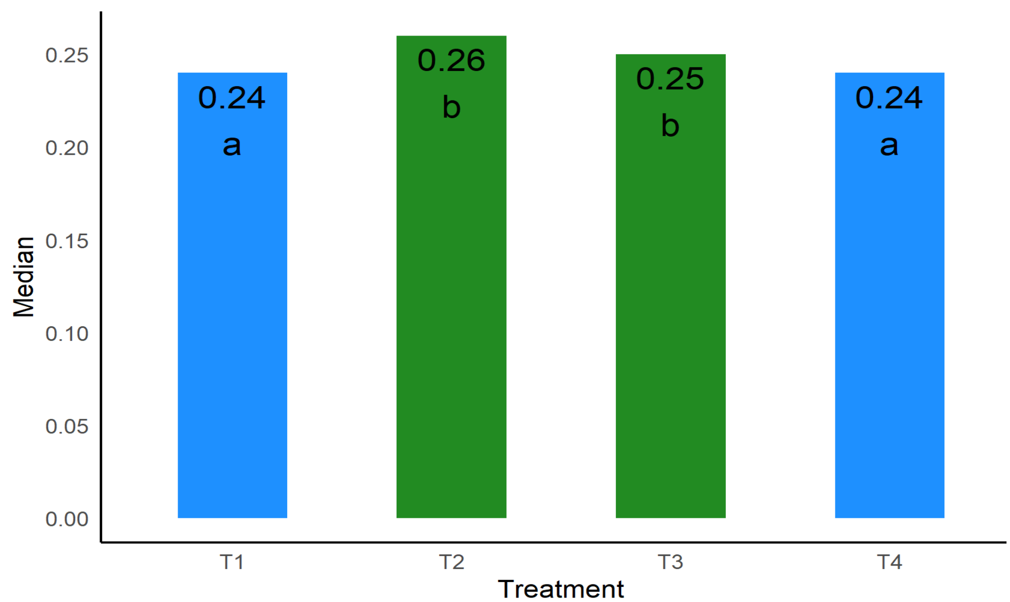

Figure 2. Chemical Parameters (columns with different letters indicate significant differences).

On the other hand, it is important to mention that in this research, the tomato crop was not affected by pests and diseases due to the applications of garlic and chili extracts on the plants in a 2:1 ratio per liter of water, in addition to the applications of neem oil solution that were applied directly to the soil of each plant. Mfarrej & Rara (2019) and Rajamani & Negi (2021) mentioned that the use of neem oil and garlic extract is effective for insect control and is also environmentally safe. Similarly, Hollensteiner *et al.* (2017) explain that the use of *B. thuringiensis* inhibits the growth of pathogens in plants due to the production of toxins that assist in the control of insects and fungi.

CONCLUSIONS

In the conditions observed in Vanegas, a village in the municipality of Sogamoso (Boyacá), the application of vermicompost (112 g) combined with a mixture of *Bacillus* genus bacteria, including *B. subtilis*, *B. thuringiensis* var. kurstaki, *B. pumilus*, and *B. amyloliquefaciens* ($1x10^8$ CFU mL^{-1}) at a dose of 3 cm^3 L^{-1} of water, applied directly to the soil of each plant for three months, increased the weight of cherry tomato fruits by 17.14% to 28.37% compared to the other treatments. With the application of the combined treatment (treatment 2) and the individual treatment of *Bacillus* bacteria (treatment 3), the availability of nutrients such as N, P, K, Ca, S, Mg, Fe, Mn, Cu, Zn, B, and Na in the fruits increased to a greater extent. Conversely, the individual application of 112 g of vermicompost (treatment 1) and the control (treatment 4) exhibited similar behavior, with the lowest nutrient contents.

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