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Comparative evaluation of tomato and lettuce cultivation under various substrates andhydroponic conditions in Peru

Evaluación comparativa del cultivo de tomate y lechuga bajo diversos sustratos y condiciones hidropónicas en Perú

Gim Keith Vilchez García[1*], Elder Jhony Huajuyat Gonzales[1], Leyter Ludim Puancha Mariaco[1],

Max Osiel Paati Ampam[1], Marli Jempekit Wajai[1]

ABSTRACT

The research evaluated the impact of different substrates on the hydroponic production of tomato (*Solanum lycopersicum var*. 'Rio Grande') and lettuce (*Lactuca sativa var. 'White Boston'* and '*Azirka*') in the greenhouse of the Instituto de Educación Superior Tecnológico Público "Santa María de Nieva - Fe y Alegría 74". Two independent experiments were conducted in a medium-technology greenhouse. In the first, the tomato was grown using three treatments: agricultural soil, coconut fiber with nutrient irrigation, and a soilless hydroponic system. In the second, two lettuce varieties were grown using an NFT hydroponic system with standardized management practices. Plant height, number of flowers, fruit weight, number of leaves, root length, and fresh biomass were measured and analyzed. The results of the first experiment indicated that tomato plants grown in a hydroponic system without substrate (T2) reached the greatest height (140.45 cm) and produced the highest number of flowers (28 ± 7.81 flowers/plant). However, fruit weight was higher in the treatment with coconut fiber and nutrient irrigation (T1), with an average of 68.43 g. In the second experiment, *Azirka* lettuce presented the greatest height with 22.87 ± 3.01cm, while *White Boston* lettuce showed greater root length (14.45 cm), greater average number of leaves (17.22), and greater fresh weight (117.40 g). These results highlight the importance of selecting adequate substrates and hydroponic systems to improve agronomic performance, which is particularly relevant in areas with limiting soil conditions. The research contributes to developing sustainable production systems in the Peruvian Amazon.

Keywords: agricultural biotechnology, hydroponics, sustainable production, protected cultivation, lowland rainforest.

RESUMEN

La investigación evaluó el impacto de diferentes sustratos en la producción hidropónica de tomate (*Solanum lycopersicum* var. "Rio Grande") y lechuga (*Lactuca sativa* var. "*White Boston*" y "*Azirka*") en el invernadero del Instituto de Educación Superior Tecnológico Público «Santa María de Nieva - Fe y Alegría 74». Se realizaron dos experimentos independientes en un invernadero de tecnología media. En el primero, se cultivó tomate utilizando tres tratamientos: suelo agrícola, fibra de coco con riego nutritivo y un sistema hidropónico sin suelo. En el segundo, se cultivaron dos variedades de lechuga utilizando un sistema hidropónico NFT con prácticas de manejo estandarizadas. Se midieron y analizaron la altura de las plantas, el número de flores, el peso de los frutos, el número de hojas, la longitud de las raíces y la biomasa fresca. Los resultados del primer experimento indicaron que las plantas de tomate cultivadas en un sistema hidropónico sin sustrato (T2) alcanzaron la mayor altura (140,45 cm) y produjeron el mayor número de flores (28 ± 7,81 flores/planta). Sin embargo, el peso del fruto fue mayor en el tratamiento con fibra de coco y riego nutritivo (T1), con una media de 68,43 g. En el segundo experimento, la lechuga Azirka presentó la mayor altura con 22,87 ± 3,01 cm, mientras que la lechuga *White Boston* mostró mayor longitud de raíz (14,45 cm), mayor número medio de hojas (17,22) y mayor peso fresco (117,40 g). Estos resultados ponen de manifiesto la importancia de seleccionar sustratos y sistemas hidropónicos adecuados para mejorar el rendimiento agronómico, lo que es especialmente relevante en zonas con condiciones edáficas limitantes. La investigación contribuye al desarrollo de sistemas de producción sostenibles en la Amazonía peruana.

Palabras clave: biotecnología agrícola, hidroponía, producción sostenible, cultivo protegido, selva baja.

[1]Instituto de Educación Superior Tecnológico Público Santa Maria de Nieva "Fe y Alegria 74", Condorcanqui, Amazonas - Perú.
*Autor de correspondencia. E-mail: gvilchez@iestpfeyalegria74.edu.pe

I. INTRODUCTION

Sustainable agricultural production has gained significant relevance in recent years, especially in the context of climate change and increasing food demand (FAO, 2021). Hydroponic systems have emerged as an efficient alternative to increase agricultural production in areas where soil conditions are not optimal, as is the case in many regions of Latin America (Yang et al., 2023; Rajendran et al., 2024; Velazquez-Gonzalez et al., 2022). These systems, which allow soilless cultivation, use various substrates to provide plant support and optimize nutrient uptake (Naresh et al., 2024). Among the most commonly used substrates are coconut fiber and mixtures with soil rice husks, which are evaluated for their ability to improve the yield of cash crops such as tomato (*Lycopersicon esculentum*) and lettuce (*Lactuca sativa*) and because they are often locally available (Guerrero et al., 2014; Guzmán et al., 2020; Silva et al., 2021).

Growing tomato and lettuce in hydroponic systems has proven to be particularly advantageous in regions such as the Peruvian Amazon, where soil limitations, such as erosion and low fertility, can restrict agricultural productivity (Ingar et al., 2023; Somerville et al., 2022). Previous research has shown that specific substrates can significantly influence the agronomic parameters of these crops, including root development, water retention, and nutrient uptake (Khan et al., 2018; Kaur and Dewan, 2023). Also, choosing the right substrate can improve plant resistance to biotic and abiotic factors, which is essential to ensure the sustainability of the production system (Leotta et al., 2023; Le and Millar, 2022).

In addition to improving productivity, hydroponic systems have been recognized for their potential to reduce the environmental impact associated with conventional agriculture. These systems minimize water use by recirculating nutrients and reducing runoff, which is especially advantageous in water-scarce regions or fragile ecosystems (Pomoni et al., 2023; Singh et al., 2024). The controlled environment of hydroponics allows for better pest and disease management, reducing the need for chemical inputs and promoting cleaner production practices (Afdhalis et al., 2023). The choice of substrate is fundamental in achieving these benefits since the physicochemical properties of substrates influence root zone conditions and microbial activity, affecting plant health and productivity (Ruiz and Salas, 2019). These advantages highlight the importance of hydroponic technologies to achieve sustainable and resilient agricultural systems, especially in areas such as the Peruvian Amazon, where environmental preservation is fundamental.

Tomato and lettuce are crops of high economic and nutritional value, and their cultivation in hydroponic systems has led to increased yields compared to traditional soil-based cultivation methods (Goh et al., 2023; Fayezizadeh et al., 2021). The physicochemical characteristics of the substrate directly affect the availability of water and nutrients, which influences growth and fruit quality in the case of tomato and leaf biomass in the case of lettuce (Ortiz-Delvasto et al., 2023; Schafer and Lerner, 2021). Studies in tropical climates have shown that substrates such as coconut fiber can offer comparative advantages due to their high water-holding capacity and adequate aeration (Londra et al., 2018), resulting in better vegetative development of plants.

In this context, the present study aims to evaluate the impact of different substrates on tomato hydroponic production and the NFT hydroponic system on two lettuce varieties, analyzing their effects on yield and agronomic traits. This analysis will identify which type of substrate offers better productivity and crop quality results, providing valuable information to improve the sustainability of cropping systems in areas with low fertility soils or restrictive characteristics.

II. MATERIALS AND METHODS

Study area

Both experiments were carried out in a medium-technology greenhouse belonging to the Instituto de Educación Superior Tecnológico Público "Santa María de Nieva - Fe y Alegría 74", located in the district of Santa María de Nieva, province of Condorcanqui, Amazonas region, Peru (coordinates:

4°35’57.10.10’‘ S and 77°52’14.00” W), at an altitude of 238 m a.s.l. (**Figure 1**).

The greenhouse has a polyethylene covering and passive lateral ventilation, conditions that allow partial regulation of the internal temperature and humidity.

Regarding the climatic characteristics of the geographical area where the greenhouse is located, the district has a humid tropical climate, with annual rainfall reaching 3,000 mm. The dry season, from July to November, is characterized by high temperatures, which can exceed 35 °C, while during the rainy season, from February to May, average temperatures drop to 25 °C, with relative humidity levels usually exceeding 90%.

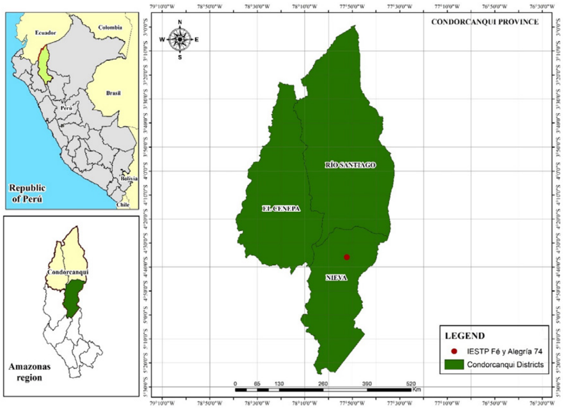

Figure 1. Geographical location of the experimental site. The experiments were conducted at the greenhouse of IESTP “Fe y Alegría 74”, located in the district of Nieva, province of Condorcanqui, Amazonas region, Peru (red dot). The map displays its relative location at the national (Peru), regional (Amazonas), and provincial (Condorcanqui) levels.

Experiment 1: Evaluation of substrates in tomato cultivation

Experimental design

The first experiment evaluated the effect of different substrates on the hydroponic cultivation of tomato (*Solanum lycopersicum var*. ‘Rio Grande’). The experimental design was completely randomized, with three treatments: T0 (agricultural soil plus conventional irrigation), T1(coconut fiber and nutrient irrigation), and T2 (hydroponic system without substrate). Five replicates per treatment were established, using 5 L pots as experimental units, and each replicate consisted of 4 plants, for a total of 60 plants in the experiment (**Figure 2**). The trial was conducted in a greenhouse where an average temperature of 25°C and relative humidity of 70% were maintained for 75 days.

Figure 2. Tomato experiment set up inside a greenhouse.

Disinfection

The work area in the greenhouse was disinfected using a solution of sodium hypochlorite and detergent, thoroughly cleaning the floors and walls to eliminate potential sources of contamination, such as fungi and bacteria that could cause diseases in the crops. The pots used for tomato production were also disinfected with a 5% sodium hypochlorite solution to prevent any affectation by pathogenic microorganisms. In addition, the substrates, such as coconut fiber and agricultural soil, were disinfected by a solarization process. This method involves exposing the substrates to the sun for three days to eliminate the pathogens present, thus ensuring a disease-free environment for the plants.

Hydroponic Irrigation Installation

The third treatment was implemented using 15-liter plastic containers, cut lengthwise and conditioned with a water inlet and outlet system using 25.4 mm pipes and 6 mm diameter hoses. A storage tank and a 2HP motor were used to ensure efficient water distribution and a constant rainwater supply. Previously, the water was subjected to quality control, where its pH was measured, and the absence of sediments was verified, optimizing the irrigation system and ensuring an adequate flow for crop development.

Substrate preparation

A sieve was designed to sieve the agricultural soil to improve irrigation conditions and aeration and favor plant root development. After this process, the containers were filled with the sieved soil. At the same time, coconut mesocarp was extracted and chopped into small particles using a machete. Subsequently, the particles were selected and mixed homogeneously to obtain a uniform substrate suitable for planting.

Germination and planting in pods

Two seedbeds were constructed using coconut fiber as a germination medium for the tomato seeds. Once germinated, the seedlings were distributed and sown in the three substrates: coconut fiber, agricultural soil, and hydroponic solution.

Once the seeds germinated, the height of the tomato seedlings was measured. When the seedlings reached a height of 10 cm, they were transplanted to the final field, which consisted of pots with different substrates.

Variables evaluated

The variables evaluated in this study included plant height and number of flowers, with measurements taken every 10 days for 50 days. Plant height was measured in centimeters using a flexible tape measure, referencing the lowest point of the stem to the plant's apex. The number of flowers per plant was counted manually, and the total number of flowers formed at each flowering stage was recorded. In the final evaluation, the weight of the fruits was determined using a precision digital scale (with a sensitivity of 0.01 g), ensuring the accuracy of the data obtained on the production of each plant, expressed in grams per plant.

Pest and disease control

Phytosanitary control was implemented using chromatic traps for pests such as whitefly (*Trialeurodes vaporariorum*) and aphids (Aphididae). Copper sulfate was applied to control fungal diseases, and the plants were regularly monitored for symptoms.

Experiment 2: Evaluation of the agronomic performance of two lettuce varieties in the NFT hydroponic system

Experimental design

A completely randomized experimental design (CRD) was used with two treatments: the lettuce varieties *'White Boston*' and '*Azirka*.' Each treatment had five replicates, each consisting of 50 plants, for 500 plants in the experiment. The plants were evenly distributed in the tubes of the NFT hydroponic system, ensuring that both varieties received the same conditions of light, temperature, and nutrient supply (**Figure 3**).

Figure 3. Installation of lettuce varieties in NFT hydroponic system.

Disinfection

Before the experiment started, materials such as germination trays and containers were thoroughly cleaned and disinfected to avoid contamination. The greenhouse was conditioned to maintain a controlled environment, guaranteeing optimal conditions for the experiment's development.

Germination

Lettuce seeds of both varieties, *Azirka* and *White Boston*, were sown in their respective labeled germination trays, using coconut fiber as substrate. The trays were placed inside technopor containers on a wooden rack, and irrigation was carried out twice a day with a small sprayer, using only water. Once 90% of the seeds germinated, a nutrient solution was applied at 50% concentration (2.5 ml of solution "A" and 1.0 ml of solution "B" per liter of water). The lettuce seedlings remained in the trays until they developed three true leaves, at which time the first transplant was carried out.

First transplanting

The first transplanting was performed 8 days after germination. For this purpose, the inside of the wooden crate was first lined with a 1.5 m long by 0.7 m wide black plastic sheet. An aquarium air pump and a 16 mm irrigation hose were used to generate a circular movement in the solution to ensure adequate aeration of the nutrient solution. A 2-inch thick technopor sheet was placed on top of this solution, divided into two sections (horizontal and vertical), maintaining a distance of 2 cm between the perforations.

Before transplanting, the roots were cleaned from the substrate, and the stems of the seedlings were placed in the center of a 3 cm x 3 cm sponge. The sponges were placed in disposable cups, which were positioned inside the perforations of the technopor plate. Eight days after transplanting to the floating root system, a 100% bolting rate was observed for the *Azirka* and *White Boston* lettuce varieties.

Second transplanting

With the hydroponic system completely constructed and the nutrient solution prepared, the second transplanting of the lettuce seedlings was carried out 20 days after germination. Each seedling was placed in the holes of the corresponding tubes. The lettuce varieties were distributed as follows: the *Azirka* variety was placed in the horizontal tubes. In contrast, the *White Boston* variety was placed in the vertical tubes to ensure an adequate comparison parameter. Once the plants reached their physiological and phenological development in the NFT culture system, harvesting and evaluation of all study parameters were carried out.

Pest and disease management

Ethological control was used to manage pests in the lettuce crop, using yellow chromatic traps covered with a TEKNO entomological adherent. This method focused on pests such as leafminer fly (*Liriomyza huidobrensis*), green aphids (*Macrosiphum euphorbiae* and *Myzus persicae*), and whitefly (*Trialeurodes vaporariorum*).

A disinfection protocol was implemented for equipment and people entering and handling the plants, ensuring the correct use of the greenhouse access chamber doors. In addition, pest and disease control mechanisms were established. These measures were key to optimizing plant nutrition and regulating temperature and oxygenation conditions in the nutrient solution, ensuring a favorable environment for the experiment's development.

Hydroponic system management

The hydroponic irrigation systems were established inside the greenhouse, where pumping equipment was installed to transport the water enriched with nutrient solution. The optimum time for a complete hydroponic water change was determined after harvest. However, in the case of the smaller hydroponic containers, it was observed that the time interval for water change was shorter.

Lettuces require high, but not excessive, humidity. During the first weeks after planting, constant irrigation was maintained every three days, ensuring the plants received natural light at all times to favor their proper development. The motor used to circulate the water was activated according to the needs of the two lettuce varieties and the changing environmental conditions.

Variables evaluated

Plant height, root length, and number of leaves were measured, with measurements taken every seven days for 21 days. Plant height was recorded with a stainless steel caliper. A 30 cm ruler measured root length, facilitating direct and reliable data collection. The number of leaves was counted manually, ensuring a careful verification of each plant to obtain consistent and representative growth results. At the end of the experiment, the fresh weight of the lettuce was determined with a precision digital scale.

Statistical analysis

For both experiments, we began by verifying the assumptions of normality and homogeneity of variance of the data using the Shapiro-Wilk and Levene tests, respectively. Subsequently, after confirming these assumptions, the data corresponding to tomato plant height and number of flowers were subjected to an analysis of variance (ANOVA), followed by a Tukey's multiple comparison test to identify significant differences between treatments. A Student's t-test for independent samples was applied to the fruit weight data. For the second experiment, all variables were analyzed using Student's t-test. All statistical analyses were performed at the 5% significance level using the statistical software InfoStat version 2018 Professional.

III. RESULTS AND DISCUSSION

Experiment 1: Evaluation of substrates in tomato cultivation

Plants grown in T2 (hydroponic system without substrate) showed the greatest heights in all evaluations, reaching a final height of 140.45 ± 11.29 cm (**Figure 4**). The highest number of flowers was observed in T2, with 28.16 ± 7.81 flowers/plant (**Figure 5A**), while the heaviest fruits were obtained in T1 (coconut fiber plus nutrient irrigation) with 68.42 ± 11.62 g (**Figure 5B**). This finding is consistent with research reporting that hydroponic systems, by providing a nutrient solution directly to the roots, optimize nutrient and water uptake, resulting in faster and more vigorous growth (Rajaseger et al., 2023; Velazquez-Gonzalez et al., 2022). In Peru, research such as that of Silva et al. (2021) also highlights the efficacy of hydroponics in tomato cultivation, where higher yields in height were observed compared to soil-grown crops.

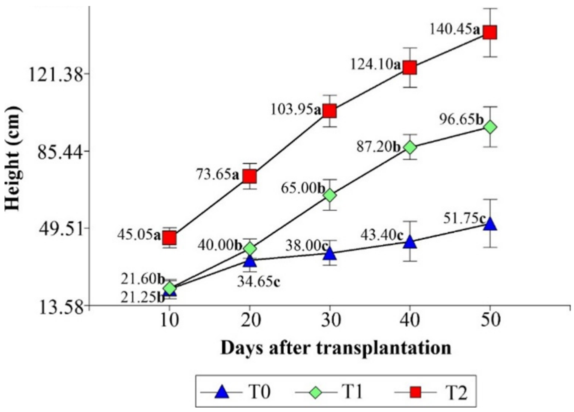

Figure 4. Tomato height according to treatments during five evaluations, different letters vertically indicate significant differences according to the Tukey test (p<0.05).

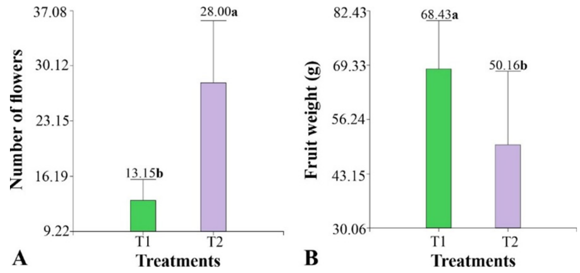

Figure 5. Number of tomato flowers (A) and fruit weight by treatments, different letters indicate significant differences according to Student's t-test (p>0.05).

The number of flowers was also higher in the hydroponic system (T2), reflecting the higher efficiency of nutrient distribution in this system (Fathidarehnijeh et al., 2024; Pignata et al., 2017). In an international context, Williams et al. (2020) pointed out that hydroponics can significantly increase reproductive performance in vegetables, including tomato, due to the constant availability of nutrients in the nutrient solution. Therefore, hydroponic systems, especially without substrate, can offer considerable advantages in terms of growth and flowering. However, using substrates such as coconut fiber may favor the development of heavier fruits.

On the other hand, although the coconut fiber treatment (T1) did not achieve the greatest heights, it favored fruit weight. This coincides with studies by Schmautz et al. (2016) that point out that coconut fiber optimizes the formation of higher-quality fruits by improving aeration and drainage.

Experiment 2: Evaluation of substrates in lettuce cultivation

Plant height increased as the evaluations elapsed, with the Azirka lettuce variety registering the highest average of 22.87 ± 3.01 cm in the final evaluation (**Figure 6**), with significant differences between evaluations and varieties.

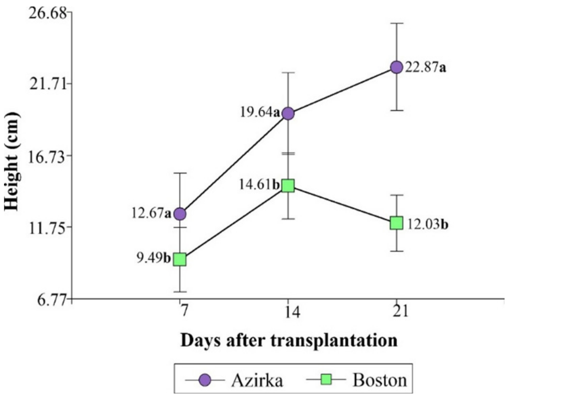

Figure 6. Lettuce height according to varieties during three evaluations. Different letters vertically indicate significant differences (Student's t, p<0.05).

Root length also differed between varieties, with the Boston variety clearly superior, which presented an average of 17.22 ± 3.08 cm in the final evaluation (**Figure 7**); this variable also increased in each evaluation. Similar results were found by Cruz (2016), who recorded a root length of 16.1 cm under Bolivian conditions.

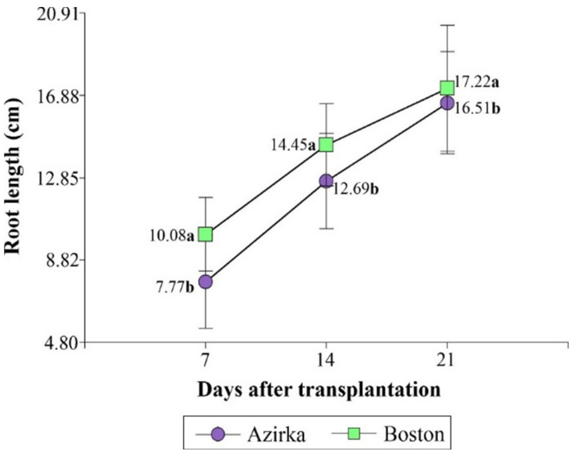

Figure 7. Root length by variety during three evaluations. Different letters vertically indicate significant differences (Student's T, p<0.05).

Regarding the number of leaves, the Boston variety was also superior, with 16.18 ± 2.76 leaves in evaluation 3 (21 days after transplanting), and both varieties increased their leaves with each evaluation (**Figure 8**).

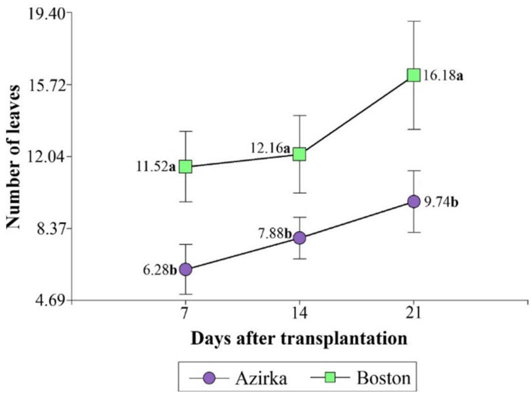

Figure 8. Number of leaves per variety during three evaluations. Different letters vertically indicate significant differences (Student's t-test, p<0.05).

Regarding the fresh weight of lettuce (**figure 9**), the Boston variety was also superior, with 117.40 ± 27.20 g. This variety's higher biomass could be due to its higher photosynthetic capacity and efficiency in using resources such as water and nutrients (Ahmed et al., 2021; Simkin et al., 2019). The results suggest that the Boston variety could be a better option in terms of fresh biomass production, which is key to improving agricultural yield and crop sustainability.

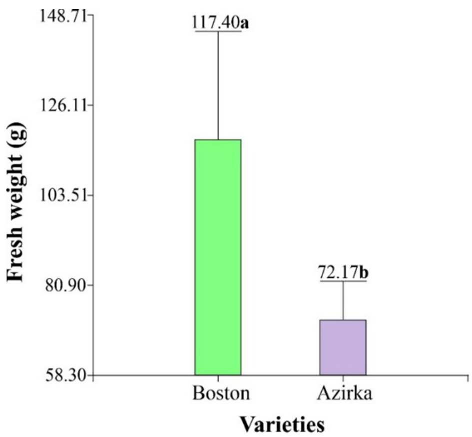

Figure 9. Fresh weight of lettuce by variety. Different letters between bars indicate significant differences (Student's t, p<0.05).

These results are aligned with studies that highlight the Boston variety's ability to develop deeper root systems, which is associated with better nutrient uptake (Mollehuanca, 2019). In Peruvian research, Leiva et al. (2018) also highlighted that lettuce varieties with greater root development tend to show better growth and a greater number of leaves, improving the final product's quality.

The progressive increase in the evaluated variables (plant height, root length, and number of leaves) throughout the evaluations suggests that the substrates used provided adequate conditions for continuous plant development. This is consistent with studies, such as those of Resh (2022), which show that using high porosity substrates, such as coconut fiber, favors balanced plant development regarding aerial and root biomass. In addition, the behavior of both varieties in different substrates suggests that, although both have high productive potentials, the Boston variety has significant advantages regarding root development, which could improve its capacity to absorb nutrients and water, a key aspect for its adaptation to intensive cultivation systems.

The results obtained in this research have important implications for managing tomato and lettuce crops under different cropping systems and substrates. In the case of tomato, hydroponic systems without substrate (T2) showed superior growth in height and number of flowers, highlighting the feasibility of implementing hydroponic cropping systems in areas where soil availability is limited. In addition, although coconut fiber did not generate the tallest plants, it favored heavier fruits, which may be key for markets that value quality over quantity.

In the case of lettuce, the results indicate that the Boston variety, with greater root length, number of leaves, and greater fresh weight, could have a competitive advantage regarding nutrient absorption in intensive cultivation systems, such as hydroponics. This is particularly relevant considering that fast-growing crops with high nutritional efficiency are sought after. These findings imply that proper selection of varieties and cropping systems could improve production efficiency and product quality.

IV. CONCLUSIONS

This research shows that hydroponic systems without substrate (T2) are highly effective for growth in height and number of flowers in tomato crops. At the same time, the use of coconut fiber (T1) favors the formation of heavier fruits. This indicates that the choice of cropping system and substrate significantly impacts the quality and quantity of tomato production.

In lettuce cultivation, the Boston variety stood out for its greater root development, number of leaves, and fresh weight, making it an ideal candidate for cropping systems that prioritize efficiency in nutrient uptake.

The conclusions of this study suggest that both variety selection and cropping systems play a crucial role in optimizing horticultural production. This provides a basis for future research on the efficiency of these systems under different soil and climatic conditions.

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