Colegio de Postgraduados

Rooting of Tomato Cuttings in Nutrient Solution or Substrate: An Alternative for High-Density Production Systems

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ABSTRACT

Objective: To evaluate the quality of tomato seedlings produced from cuttings rooted in a nutrient solution and in solid substrates (peat moss, red volcanic rock, and a mixture of both substrates), and to determine their subsequent effects on plant growth and yield.

Design/methodology/approach: Cuttings were collected from 80-day-old mother plants. After treatments were established, rooting was conducted inside a controlled structure maintained at 15-20 °C and 70% relative humidity (RH). Irrigation was applied automatically every hour for two minutes using a nutrient solution at 50% strength. The experimental design was a randomized complete block design (RCBD) with four replications. Growth variables were recorded 20 days after rooting initiation and at the onset of harvest. Subsequently, yield and its components were assessed.

Results: All seedlings met quality standards at transplanting; however, seedlings derived from cuttings rooted in nutrient solution exhibited significantly greater stem diameter (7.3 mm), leaf area (354.5 cm²), and dry weight (3.1 g). Nonetheless, at the adult plant stage, no differences in growth or yield were detected among treatments.

Limitations on study/implications: An economic feasibility analysis is required for each substrate evaluated.

Findings/conclusions: For seedling production, rooting in nutrient solution or in a 1:1 (v/v) mixture of peat moss and red volcanic rock constitutes a more viable option in terms of cost-effectiveness and accessibility.

Keywords: Tomato cuttings, nutrient solution, substrates, seedling quality.

Citation: Sánchez-Del Castillo, F., Mejía-Betancourt, F. de los Á., Moreno-Pérez, E. del C., & González-Molina, L. (2026). Rooting of Tomato Cuttings in Nutrient Solution or Substrate: An Alternative for High-Density Production Systems. *Agro Productividad*. https://doi.org/10.32854/6ftdea19

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Juan Francisco Aguirre Medina

Received: June 6, 2024.
Accepted: January 3, 2026.
Published on-line: April XX, 2026.

Agro Productividad, 19(2). February. 2026. pp: 97-105.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is the most widely cultivated horticultural species under protected cultivation in Mexico (SIAP, 2023; USDA, 2024). Within tomato production systems, the nursery stage is particularly critical, because seedling quality directly determines the number of flowers and fruits set in the first trusses (Gaytán-Ruelas

et al., 2016; Moreno-Pérez *et al.*, 2021). The cost of seedlings destined for greenhouse management is high, primarily because hybrid seeds and relatively expensive substrates are typically used for sowing (Moreno *et al.*, 2021; Mejía *et al.*, 2023). In Mexico, the substrate most commonly used for tray-based seedling production is sphagnum peat moss, either alone or combined with perlite. Both materials exhibit physical and chemical properties that promote optimal seedling growth due to their high capacity for water retention and root-zone oxygen availability (Lazcano-Bello *et al.*, 2021). Nevertheless, both substrates are costly (Ortega-Martínez *et al.*, 2010), a constraint that becomes even more pronounced in production systems operating at high plant densities, as proposed by Sánchez-Del Castillo *et al.* (2010), Sánchez-Del Castillo *et al.* (2012), and Moreno-Pérez *et al.* (2021). In such systems, up to 80,000 plants ha^{-1} may be established in a four-month crop cycle, and as many as 240,000 seedlings ha^{-1} $year^{-1}$ when three crop cycles per year are implemented. Accordingly, the present study proposes the use of rooted cuttings as a substitute for conventional botanical seed propagation (Moreno-Pérez *et al.*, 2016; Mejía-Betancourt *et al.*, 2023), together with the use of low-cost media such as tezontle sand (red volcanic rock) for rooting and/or transplant production, or even the use of a nutrient solution as a rooting medium in place of the high-cost substrates commonly employed (Ortega-Martínez *et al.*, 2010; Moreno-Pérez *et al.*, 2016; Cheiri *et al.*, 2018; Urrestarazu-Gavilán, 2023). Based on this rationale, the objective of this work was to evaluate the quality of tomato seedlings obtained from cuttings rooted in different solid substrates or in a nutrient solution, and to determine their effects on plant growth and yield at the end of the cropping cycle. The hypothesis is that seedlings produced from cuttings rooted in nutrient solution will exhibit high transplant quality and comparable if not superior productive performance relative to those rooted in substrate, given that immediate nutrient availability in solution may optimize development while reducing production costs. In addition, it is proposed that combining fine tezontle sand with peat moss may be ideal for rooting cuttings, because tezontle provides high moisture retention, whereas peat moss enhances root-zone aeration.

MATERIALS AND METHODS

Site and biological material

The nursery phase was conducted in a 300 m^2 greenhouse located at the Experimental Field of the Universidad Autónoma Chapingo. This greenhouse was equipped with a high light-diffusion thermal polyethylene cover, anti-aphid insect-proof screens, and a climate-control system consisting of heating, a wet wall, and exhaust fans to regulate temperature and relative humidity. Subsequent crop management was performed in a separate 500 m^2 greenhouse with characteristics similar to those of the nursery facility. The tomato hybrid 'Pai Pai' (Enza Zaden), a saladette-type cultivar with an indeterminate growth habit, high yield potential, and broad adoption among growers, was used.

Experimental design and treatments

A randomized complete block design (RCBD) was implemented with four treatments and four replications, using 10 plants per experimental unit. The treatments (Figure 1) were as follows:

Treatment 1: Rooting of cuttings in nutrient solution. A plastic tray (25 cm wide × 50 cm long × 20 cm deep) was filled with a 50% strength nutrient solution containing the following nutrients (mg L^{-1}): N=200, P=50, K=250, Ca=300, S=150, Mg=50, Fe=2, Mn=1, Cu=1, Mo=0.5, B=0.5, and Zn=0.5. A perforated polystyrene (Styrofoam) sheet with holes spaced 10 cm apart in both directions was placed over the tray, and tomato shoots were inserted into the holes for rooting.

Treatment 2 (control): Rooting of cuttings in 60-cell trays (200 cm^3 per cell) filled with peat moss as the substrate.

Treatment 3: Rooting of cuttings in 60-cell trays (200 cm^3 per cell) filled with fine red tezontle (red volcanic rock) sand (particle size 1-3 mm in diameter).

Treatment 4: Rooting of cuttings in 60-cell trays filled with a 1:1 (v/v) mixture of fine tezontle sand and peat moss.

Variables evaluated

At 20 days after cutting rooting, seedlings were assessed for: plant height (cm), measured from the root collar to the apical shoot; stem diameter (mm), measured between the second and third leaves; leaf area (cm^2), using a LI-3000A leaf area meter (LI-COR, Lincoln, Nebraska); root volume (cm^3), determined by the water-displacement method in a graduated cylinder; and dry weight (g), obtained by oven-drying seedlings at 70 °C for three days.

At the onset of harvest (90 days after transplanting), plants were evaluated for: plant height (cm), measured from the root collar to the terminal topping point; stem diameter (mm), measured below the second basal leaf; plant width (cm), recorded at the widest point without manually extending the leaves; and leaf area index (LAI), calculated by multiplying the leaf area per plant by the plant density (plants m^{-2}) in the greenhouse, using a LI-3000A leaf area meter (LI-COR, Lincoln, Nebraska). In addition, the number of flowers and fruits per plant, mean fruit weight (g), and yield per plant (kg $plant^{-1}$) were determined.

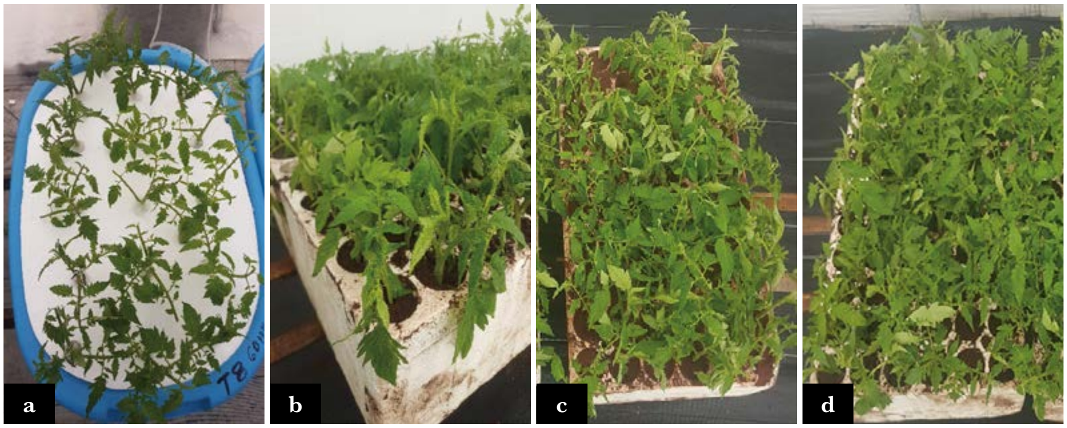

Figure 1. Treatments evaluated: (a) T1 (rooting of cuttings in nutrient solution), (b) T2 (rooting of cuttings in peat moss), (c) T3 (rooting of cuttings in fine red tezontle [red volcanic rock]), and (d) T4 (rooting of cuttings in a mixture of peat moss + fine red tezontle).

Experimental management

For the rooting of tomato cuttings (shoots), the methodology described by Mejía-Betancourt *et al*. (2023) was followed, with the following adaptations:

a) Shoots were collected from 80-day-old mother plants (Figure 2).
b) Inside a greenhouse, a structure measuring 10 m long × 3 m wide × 2.5 m high was constructed using agribon mesh and smooth galvanized wire. The structure was equipped with a water tank containing nutrient solution, a pump, piping, low-pressure misting nozzles, and metal stands to support the trays (Figure 3).
   Misting nozzles were installed at 1.3 m intervals to deliver irrigation (50% strength nutrient solution) to cuttings during rooting, applied every 2 h for 2 min. Internal temperature was maintained between 15 and 20 °C, and relative humidity (RH) between 70 and 80%.

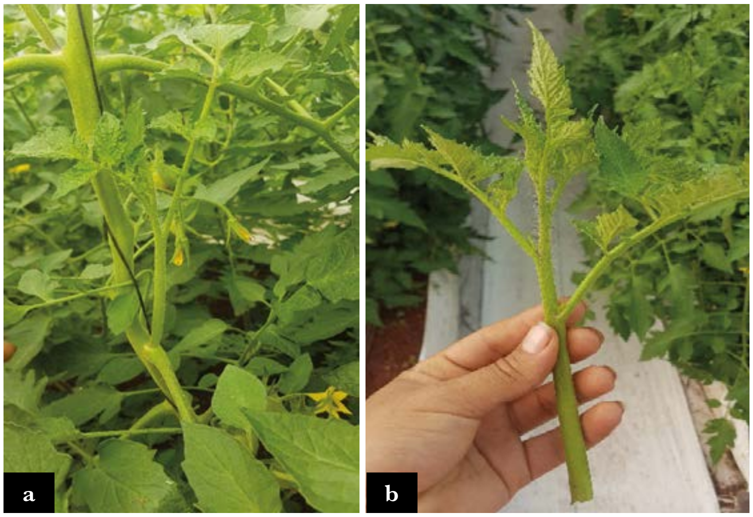

Figure 2. Collection of a lateral shoot with the ideal characteristics for rooting: (a) mother plant and (b) shoot selected for rooting.

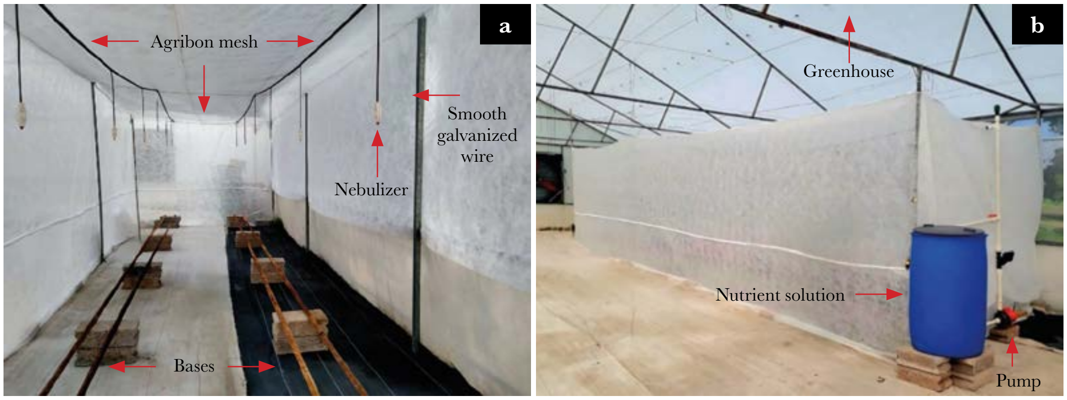

Figure 3. Cutting-rooting structure: (a) interior view and (b) exterior view.

c) A 5-day acclimation phase was subsequently conducted under standard greenhouse conditions. Two irrigations per day were applied using full-strength (100%) nutrient solution, one at 09:00 and another at 14:00 h. In the treatment in which cuttings were rooted directly in nutrient solution, aeration was provided using an aquarium air pump (Figure 4).

Transplanting was performed 20 days after cutting rooting. Crop beds 1 m wide were used, filled with red tezontle (red volcanic rock) sand as the substrate (particle size 1-3 mm). Plants were trained to a single stem at a density of 7 plants m^{-2} of greenhouse area, and when the third inflorescence had formed, the terminal bud was removed, leaving two leaves above the third truss (Figure 5). Pollination was performed manually by shaking the wires supporting the training strings. Irrigation was applied using flexible polyethylene drip tape with integrated emitters spaced every 20 cm.

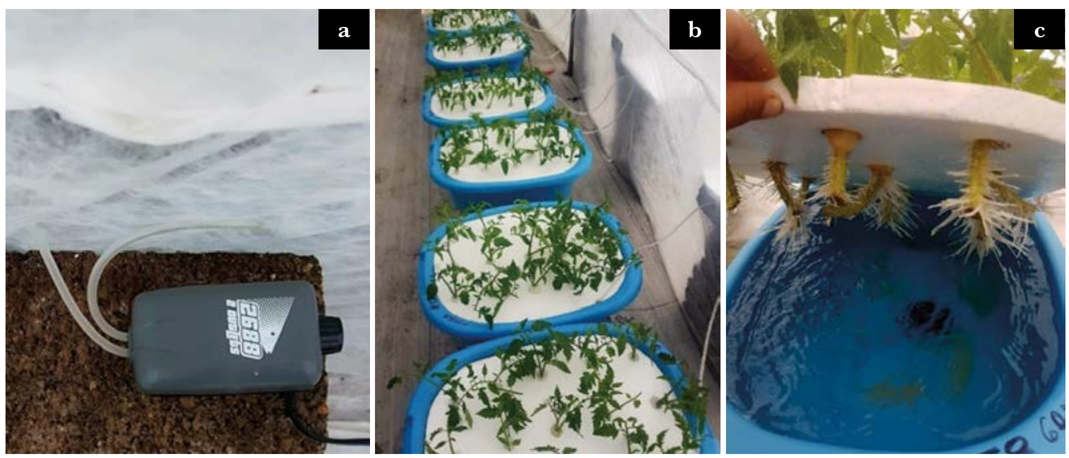

Figure 4. Aeration in Treatment 1: (a) aquarium air pump, (b) nutrient-solution treatment with oxygen supplementation, and (c) developing roots.

Figure 5. (a) Tomato plant topped at three trusses and (b) plant with two leaves above the third truss.

Data analysis

Data were first examined to verify compliance with the normality assumption. Subsequently, the variables were subjected to analysis of variance (ANOVA), and treatment means were compared using Tukey's test ($P \leq 0.05$), employing the Statistical Analysis System (SAS) for Windows, version 9.4.

RESULTS AND DISCUSSION

Variables evaluated at the seedling stage

The analysis of variance for the variables assessed at the seedling stage (data not shown) indicated a highly significant treatment effect for all measured variables, except root volume. Seedling height was greater in plants grown in peat moss than in those rooted in nutrient solution (Table 1 and Figure 6); no statistical differences were observed among the remaining treatments. Table 1 also shows that root volume did not differ among treatments. However, stem diameter, leaf area, and dry weight tended to increase in seedlings derived from cuttings rooted in nutrient solution, including statistically significant differences relative to the tezontle-only treatment. This response may be attributed to the fact that,

Table 1. Comparison of treatment means for rooting treatments in tomato seedlings (cv. Pai Pai).

Treatment	Height (cm)	Stem diameter (mm)	Leaf area (cm^2)	Root volume (cm^3)	Dry weight (g)
Nutrient solution	18.8 b	7.3 a	354.5 a	5.1 a	3.1 a
Peat moss	24.5 a	5.7 b	251.1 ab	3.1 a	2.0 ab
Fine red tezontle	19.6 ab	5.6 b	207.2 b	2.5 a	1.7 b
Tezontle + peat moss	22.6 ab	6.1 ab	269.6 ab	3.9 a	2.3 ab
LSD	5.3	1.9	129.1	2.9	1.3

Values with the same letter within each column are equal according to Tukey's test at a $P \leq 0.05$. LSD=Least significant difference.

Figure 6. Differences in seedling height as affected by treatment: (a) nutrient solution, (b) peat moss, (c) red tezontle, and (d) tezontle + peat moss mixture.

under nutrient-solution rooting, seedlings received a continuous supply of water and nutrients, as well as adequate root-zone oxygen provided by the air pump. In contrast, seedlings grown in tezontle may have experienced substrate compaction, which can impair water and nutrient uptake and reduce aeration, as reported by Vargas-Tapia *et al.* (2008), Urrestarazu-Gavilán (2004), and Urrestarazu and Carrasco (2023).

The results indicate that the use of a nutrient solution and a 1:1 (v/v) mixture of fine tezontle and peat moss are viable alternatives for rooting tomato cuttings, enabling the production of high-quality seedlings at reduced costs, as reported by Abad *et al.* (2005) and Lazcano-Bello *et al.* (2021). Although peat moss provides high moisture retention and adequate root-zone aeration, its high price reduces profitability for growers (Nava-Pérez *et al.*, 2019; Cheiri *et al.*, 2018). In addition, its use has been associated with negative environmental impacts (Muro *et al.*, 2005; Fernández-Bravo *et al.*, 2006).

Variables evaluated at the reproductive stage

Analyses of variance for reproductive-stage variables (data not shown), together with mean comparisons (Tables 2 and 3), indicated that none of the evaluated variables differed significantly among treatments.

In absolute terms, the highest yield (2.5 kg) was obtained when cuttings were rooted in the fine tezontle + peat moss mixture, corresponding to 17.5 kg m^{-2} in a production cycle lasting four months from transplanting to the end of harvest. Comparable yields have been

Table 2. Comparison of treatment means for rooting treatments in morphological variables evaluated in tomato plants at the reproductive stage.

Treatment	Height (cm)	Stem diameter (mm)	Leaf area index (m^2 m^{-2})	Plant width (cm)
Nutrient solution	88.1 a	14.4 a	3.6 a	40.5 a
Peat moss	92.7 a	14.6 a	4.1 a	41.8 a
Fine red tezontle	92.3 a	13.9 a	4.4 a	42.4 a
Tezontle + peat moss	96.3 a	14.2 a	4.3 a	44.3 a
LSD	11.1	2.2	0.9	4.7

Values with the same letter within each column are equal according to Tukey's test at a $P \leq 0.05$. LSD=Least significant difference.

Table 3. Comparison of treatment means for rooting treatments in yield and its components in tomato plants.

Treatment	Number of flowers	Number of fruits	Fruit weight (g)	Yield (kg $plant^{-1}$)
Nutrient solution	20.0 a	19.1 a	114.0 a	2.19 a
Peat moss	19.5 a	19.2 a	123.8 a	2.33 a
Fine red tezontle	20.3 a	19.2 a	112.3 a	2.16 a
Tezontle + peat moss	21.6 a	20.9 a	121.4 a	2.54 a
LSD	3.0	2.8	20.1	0.45

Values with the same letter within each column are equal according to Tukey's test at a $P \leq 0.05$. LSD=Least significant difference.

reported by Sánchez-Del Castillo *et al.* (2021) and Moreno-Pérez *et al.* (2021) for tomato plants established at high population densities using botanical seed propagation.

The results of this study suggest that the use of readily available substrates and the implementation of nutrient solution as a rooting medium for tomato cuttings constitute an economically viable option for tomato producers, while also facilitating crop management under high plant-density systems.

CONCLUSIONS

Rooting tomato cuttings in nutrient solution or in a 1:1 (v/v) mixture of peat moss and tezontle enables the production of high-quality seedlings at low cost, thereby providing a feasible alternative for managing tomato crops at high population densities.

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