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PINE BARK RATIO IN SUBSTRATE FOR CITRUS ROOTSTOCK NURSERY PRODUCTION

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ABSTRACT

Fruit tree cultivation requires rootstocks that are resistant to both biotic and abiotic stresses. The container size and substrate used are essential components in their development. Despite this, there are few studies on the impact of substrates on plant development in citrus trees under nursery conditions. This study aimed to assess the effects of three different ratios of pine bark in the substrate of three developing citrus rootstocks in a protected environment (greenhouse). The study conducted at the Cazones Nursery in Cazones de Herrera, Veracruz, Mexico, hypothesized that an increase in bark proportion would lead to a rise in the physical and chemical characteristics of the substrate and the development of the three rootstocks. The study utilized a completely randomized design with a factorial arrangement (A × B). Factor A (rootstock) had three levels: *Citrus aurantium* L. (Sour Orange), *C. volkameriana* Pasq. (Volkamer Lemon), and *C. sinensis* L. × *Poncirus trifoliata* L. (Citrage C-35). Factor B (substrate) had four levels (0, 10, 20, and 30 % pine bark), resulting in 12 treatments with 20 repetitions each. The physical and chemical characteristics of the substrates were determined, and the plant height and stem diameter were measured. Pine bark positively affected the apparent and real densities, total porosity, electrical conductivity, and cation exchange capacity. The growth dynamics of the three rootstocks were greater during the second and third months after grafting. When grown in substrates with a total porosity of 46–54 %, Volkamer Lemon, Citrage C-35, and Sour Orange rootstocks reached a plant height of 124.1, 110.5, and 84.5 cm, respectively; the stem diameter reached 6.9 mm. Porosity and cation exchange capacity increased when pine bark was added to the substrates. By evaluating the substrates and managing them proportionally, it is possible to obtain plants suitable for grafting (with 5 to 6 mm of stem) within four months after transplanting. This results in less time spent in the nursery and reduced costs.

Keywords: *Citrus*, growth dynamics, substrate characterization.

INTRODUCTION

In Mexico, fruit tree production in nurseries has traditionally been carried out in open environments (Soto-Plancarte *et al*., 2015; Barra *et al*., 2016) without knowledge of the genetic origin of the rootstock and cultivar. This propagation method increases the

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risk of pest infestations and the spread of diseases. Production has been carried out in protected spaces (greenhouse) using substrates in containers to ensure phytosanitary quality and improve establishment and development in the field (Haase *et al*., 2021).

The substrate can be of mineral origin (perlite, vermiculite, sand, tezontle, and tepetzil), organic origin (peat moss, compost, coconut fiber, rice, and coffee husks), or subproducts of industrial-forestry activities such as pine bark. To achieve the physical and chemical characteristics required for optimal plant development in containers, nurseries use three to four material mixtures. These are designed to provide the necessary porosity, electrical conductivity, moisture retention, particle size, pH, and cation exchange capacity (Ceccagno *et al*., 2019).

In Mexico, due to its physical and chemical characteristics, peat is commonly used as the main component in forestry and ornamental nurseries, along with agrolite and vermiculite (Fascella, 2015). However, pine bark could replace peat, which is imported and extracted from natural sources (Urák *et al*., 2017). Pine bark increases total porosity, water availability, and nutrient absorption when mixed with organic and mineral components. This favors root development and plant growth and reduces damage from pathogens by not providing ideal conditions for their development and proliferation (Altland *et al*., 2014).

Rootstocks are utilized in fruit trees to hasten and enhance production, provide pest and disease tolerance, and improve fruit quality (Shafqat *et al*., 2019). The agronomic and phytosanitary quality of the plant is critical for its subsequent behavior in the field. Similarly, the substrate and bag size components are crucial to plant development in the nursery (Correa-Moreno *et al*., 2022). This study aimed to assess the impact of different proportions of pine bark in the substrate on the growth of three citrus rootstocks during the nursery stage under greenhouse conditions. The hypothesis is that increasing the proportion of pine bark will improve the physical and chemical characteristics of the substrate, leading to enhanced development of the rootstocks.

MATERIALS AND METHODS

Study area location

The research occurred between June 6 and December 6, 2021, in a protected area within the certified Cazones Plant-Producing Nursery (UPC 30033065/2016) in Cazones de Herrera, Veracruz, Mexico (20° 40′ N, 97° 28′ W, at an altitude of 10 m). The climate is tropical, warm, and subhumid, with an average annual rainfall of 1200 mm and an average yearly temperature of 25 °C. The experiment utilized plants from a certified seed-producing orchard (3033066/2016) at the Cazones nursery. The plants were germinated in plastic trays measuring 45 x 32 x 12 cm with a peat, perlite, and agrolite substrate in a 6:2:2 ratio (v:v:v). Each seed was sown individually, with the hilum facing down. When the plants had between two and four true leaves, they were transplanted into 120 mL tubes with the same substrate. Additionally, Osmocote Plus® fertilizer (15N-9P-12K) was added, which has a release period of 5 to 6 months.

Plant material and treatments

The study utilized three-month-old rootstock plants derived from seeds: 80 from Sour Orange (*Citrus aurantium* L.), 80 from Volkamer Lemon (*C. volkameriana* Pask.), and 80 from Citrange C-35 (*C. sinensis* L. × *Poncirus trifoliata* L.). The plants measured 21.26 cm and 1.78 mm, 27.14 cm and 2.03 mm, and 30.67 cm and 2.05 mm in height and stem diameter, respectively. Subsequently, they were transplanted into 4 L black polyethylene bags.

Four substrates were used in the experiment (Table 1). The first substrate was used as a control, which consisted of river valley soil (RV) and tepetzil (Tz) obtained from the region and used by the Cazones nursery. River valley soil is typically found in flood plains and has a lower silt content and a higher sand percentage. This soil contains goethite as the primary mineral (Arce and Rivera, 2018). Tepetzil has a discontinuous crystalline structure and high porosity due to the presence of clays (Vizcarra-de los Reyes, 2020). To increase the total porosity of the control, pine bark (PB) was added to substrates two, three, and four at 10, 20, and 30 %, respectively (Altland *et al.*, 2014).

Table 1. Substrates used for the growth of three citrus rootstocks under nursery conditions**.**

Substrate	Components	Proportion (v:v)
1	C (RV:Tz)	3:1
2	C:PB	9:1
3	C:PB	8:2
4	C:PB	7:3

C: control; RV: river valley soil; Tz: tepetzil; PB: pine bark.

Management

During the transplanting process, the roots of the plants were trimmed to standardize their size and facilitate their placement into the bags using number 2 pruners (FELCO®, Switzerland). To prevent the spread of diseases, both the tool and the roots were disinfected using quaternary ammonium salts (1 g L^{-1}) (Timsen Biologics). Osmocote Plus® fertilizer (15N-9P-12K) with a 5–6 month release (2 g per plant) was applied. The pine bark used in this study was sourced from *Pinus patula* Schiede ex Schltdl. et Cham. and was composted for six months.

Four agrochemical applications were carried out during the research, as established by the Cazones Nursery. These included the application of 1) Raízal 400® (a root growth stimulant) at a concentration of 2 g L^{-1}, 15 days after transplanting; 2) DAP® [$(NH_4)_2HPO_4$, 18N-46P-00K, 2 g L^{-1}]; 3) Nitrofoska® (12N-8P-16K+3MgO, 2 g L^{-1}) applied 90 days after transplanting; and 4) Humic + N® (13N-7P-7K, 2 mL L^{-1}; Nasa Agro Organics) applied 150 days after transplanting. To avoid competition with the main shoot, lateral shoots were periodically removed. Irrigation was applied manually every four days using a graded container: 100 mL per plant in the first month, 350 mL per plant in the second month, and 600 mL per plant from the third to the sixth month.

Study variables

Plant height (cm) was measured from the surface of the soil of the stem to the apex, while diameter was measured at 10–15 cm above the soil surface every 28 days, starting from the first month after transplant until the end of the six-month experiment. Plant height and stem diameter were measured using a measuring tape (Truper® FH-8M, Mexico) and a caliper (Truper® Digital calibrator, Mexico), respectively.

Before the experiment, the physical characteristics of the substrate, including grain size, apparent density (Ad), true density (Td), total porosity (TP), and electrical conductivity (EC), were determined. Additionally, the chemical properties of the substrate, including pH and cation exchange capacity (CEC), were evaluated at the beginning and end of the research. These evaluations were conducted at the Soil Physics and Plant Nutrition laboratories of the Soil Science Program at the College of Postgraduates in Texcoco, State of Mexico, Mexico.

The grain size was determined on the four substrates using 500 g per sample and seven sieves with the following mesh sizes (mm): 6.36, 4.76, 3.36, 2, 1, 0.5, 0.25, and the receiver. The TP was determined by measuring the mass of water required to saturate a soil sample of a known total volume. The Ad was determined using the probe method, and the Td was determined using the water pycnometer method (Teixeira *et al*., 2017); pH, EC, and CEC were measured using standard methods. The pH was measured using a potentiometer with a substrate-to-distilled-water ratio of 1:2 (v:v). EC was measured using a conductometer with the extract and saturation method, while CEC was measured using the ammonium acetate method (Page *et al*., 1983).

Experimental design

A factorial arrangement A × B was utilized, where factor A represented the three rootstocks and factor B represented the four substrates. The substrates included three incorporating pine bark at 10, 20, and 30 %, and a control without pine bark. Each of the 12 resulting treatments had 20 repetitions (240 experimental units), distributed completely at random. The experimental unit consisted of one plant of each rootstock (described earlier) in a black, 4 L polyethylene bag. Analyses of variance and mean tests were conducted (Tukey, $p \leq 0.05$) for the variables plant height (cm) and stem diameter (mm). The data were processed using R-4.2.1® software.

RESULTS AND DISCUSSION

Physical characteristics of the substrates before the experiment

Grain size

The substrates used in the experiment exhibited varying grain sizes (Table 2), resulting in different porosity levels. This, in turn, directly affects the availability of water and oxygen for the roots of the established plants.

Table 2. Physical characteristics of the four substrates used to assess the effects of different ratios of pine bark on the development of citrus rootstocks, measured before the experiment.

Substrate*	Grain size (%)								Ad	Td	TP
	Mesh number							Receiver	(g cm^{-3})		(%)
	6.36	4.76	3.36	2	1	0.5	0.25				
1	4.3	2.1	10.4	9.8	7.1	8.4	8.9	49.0	1.26	2.4	46
2	2.2	1.7	7.4	8.3	9.0	7.3	7.3	56.7	1.23	2.3	48
3	2.8	1.5	7.9	9.7	9.9	7.3	7.5	53.2	1.19	2.2	50
4	3.3	1.3	8.5	9.0	10.4	8.0	8.4	51.1	1.05	2.1	54

RV: river valley soil; Tz: tepetzil; PB: pine bark; Ad: apparent density; Td: true density; TP: total porosity. *Substrate 1: control, RV:Tz, 3:1 (v:v); substrate 2: C:CP, 9:1 (v:v); substrate 3: C:CP, 8:2 (v:v); substrate 4: C:CP, 7:3 (v:v); *n* = 4.

The addition of pine bark was projected to reduce the weight of particles in the receiver from substrate 1 to substrate 4 by 10 to 30 %. However, this trend was only observed from substrates 2 to 4, with substrate 1 having the lowest percentage in the receiver. This is because all meshes included a higher percentage of tepetzil particles, indicating that the pine bark particles were smaller. Schäfer and Lerner (2022) state that for container vegetable production, substrates should consist of particles between 3.5 and 8 mm. Smaller particles promote a greater release of ions into the solution and increase electrical conductivity.

The following results were obtained for coarse (≥ 2 mm), medium (0.5–2 mm), and fine particles (≤ 0.5 mm in weight) (Khamare *et al.*, 2022). Coarse particles: substrate 1 (17.3 %), substrate 2 (14.6 %), substrate 3 (14.8 %), and substrate 4 (16.4 %); medium particles: substrate 1 (16.9 %), substrate 2 (17.3 %), substrate 3 (17.2 %), and substrate 4 (19.4 %); and fine particles: substrate 1 (16.8 %), substrate 2 (11.3 %), substrate 3 (12.2 %), and substrate 4 (13.1 %). Given the lack of specific recommendations for citrus and the results of this study, the percentages generated could serve as a reference for developing the three rootstocks in nursery conditions.

Apparent (Ad) and true (Td) densities

According to Martínez and Roca (2011), the apparent density for plant production in pots should not exceed 0.75 g cm^{-3}. The values obtained for Ad in the substrates evaluated in this study exceeded the limit, possibly due to the inclusion of valley soil, known for its small particles. However, these values decreased with the addition of pine bark, as demonstrated in substrates 2 and 4. Additionally, the total porosity values increased (Table 2). The apparent density of a substrate depends on its particle size. An increase in apparent density can cause salinity and compaction in the substrate (Soto-Bravo and Betancourt-Flores, 2022).

According to Martínez and Roca (2011), the density of organic materials is around 1.45 g cm^{-3}, while minerals have a density of 2.65 g cm^{-3}. Values within this range are considered optimal. For the present study, the values vary from 2.1 to 2.4 g cm^{-3} (Table 2).

Total porosity (TP)

There are no specific recommendations regarding the total porosity of the substrate used in citrus plants. However, it has been suggested that for potted ornamentals and horticulture, values should range from 70 to 80 % (Sánchez-Cardozo and Díaz-Barrera, 2019). These values have been determined on peat, vermiculite, and perlite substrates. Fields *et al.* (2021) noted that pine bark TP varies depending on particle size. Substrates with particles ≤ 16 mm, ≤ 6.3 mm, and >12.6 mm show 78, 79, and 81 % TP, respectively. However, the values obtained (Table 2) are lower than those reported, possibly due to 50 % of the samples being composed of valley soil, which consists of small particles. On the other hand, substrate 1 (control) had a higher percentage of tepetzil particles in all meshes but had the lowest porosity percentage. This indicates that incorporating pine bark improves this parameter. Based on the observed response and the satisfactory development of the three rootstocks used, which were adequate for grafting four months after transplant, we can conclude that they require a 46 to 54 % TP to develop in a greenhouse environment.

Electrical conductivity (EC)

Furlani *et al.* (2009) recommend EC values of 2–2.5 dS m^{-1} for citrus rootstock growth. Bataglia *et al.* (2005) compared two fertilization management systems (fertigation and slow-release fertilization) in citrus rootstocks with a pine bark and vermiculite substrate. They found that values increased from 2 to 5 dS m^{-1} throughout the growth period due to salt accumulation from fertilization. The study shows a decrease in EC from the start to the end of the experiment for all substrates (Table 3), indicating that adding pine bark reduced EC. However, there were no significant effects on the development of the three rootstocks. To avoid toxicity problems, substrates should have a low EC and controlled nutrient concentration (Bataglia *et al.*, 2005).

Chemical characteristics of the substrates

pH

Arce and Rivera (2018) state that the optimal pH range for producing citrus rootstocks in pots ranges from 5.5 to 6, which maximizes nutrient availability. A slight increase in pH values for all substrates (Table 3) was registered at the end of the experiment, which can be attributed to irrigation, fertilization, and management. Regarding the incorporation of pine bark, no defined tendency was observed. Therefore, we can claim that it did not affect the pH of the substrates during the evaluation period. However, the pH values are above the range indicated as optimum for nutritional availability. This may be related to 50 % of the sample being composed of valley land, which characteristically has a neutral pH (Arce and Rivera, 2018). During plant development, substrate variations may occur due to management practices such as irrigation, fertilization, and differences between species (Schäfer *et al.*, 2008). It can be concluded that these pH values (Table 3) do not limit the development of the three rootstocks under nursery conditions in greenhouse environments.

Table 3. Chemical characteristics and electrical conductivity of four substrates used to assess the effects of different ratios of pine bark on the development of citrus rootstocks, at the beginning and the end of the experiment.

Rootstock	Substrate*	pH	EC (dS m^{-1})	CEC ($cmol_c$ kg^{-1})
		Before the experiment		
	1	7.69	3.06	16.5
	2	7.70	3.13	21.7
	3	7.70	3.86	20.7
	4	7.70	2.34	22.7
		After the experiment		
Sour Orange	1	7.92	2.55	20.71
	2	7.92	2.35	19.61
	3	7.95	2.18	22.30
	4	8.00	1.71	23.20
Volkamer Lemon	1	8.04	2.41	18.58
	2	8.05	2.35	20.12
	3	8.05	1.96	22.30
	4	7.93	1.98	23.73
Citrange C-35	1	7.89	3.54	20.18
	2	7.98	2.26	19.09
	3	7.96	2.29	18.05
	4	7.95	2.03	25.28

RV: river valley soil; Tz: tepetzil; PB: pine bark; EC: electrical conductivity; CEC: cation exchange capacity. *Substrate 1: control, RV:Tz, 3:1 (v:v); Substrate 2: C:CP, 9:1 (v:v); Substrate 3: C:CP, 8:2 (v:v); Substrate 4: C:CP, 7:3 (v:v); $n = 4$.

Cation exchange capacity (CEC)

The substrates generally had optimal CEC values, as Schäfer *et al.* (2008) reported, with values greater than 20 $cmol_c$ kg^{-1}. However, some exceptions existed, such as substrate 2 in Sour Orange, substrate 1 in Volkamer Lemon, and substrates 2 and 3 in C-35 (Table 3). The final CEC values were higher than the initial values, indicating that management practices positively impacted this variable. Altland *et al.* (2014) noted that the variation in results between substrates can be attributed to differences in the distribution of pine bark particle sizes. They evaluated the CEC in different particle sizes of pine bark and found that as the percentage of coarse particles (> 2 mm) decreases, CEC values also decrease, obtaining CEC values ranging from 21.3 to 46.5 $cmol_c$ kg^{-1} in pine bark. This coincides with the findings of this investigation, where substrates 2, 3, and 4 had the lowest percentages of particle size > 2 mm and the greatest CEC.

Plant height (cm) and stem diameter (mm)

Statistical differences ($p \leq 0.05$) were observed for the plant height and stem diameter variables for the rootstock factor (Table 4). This finding is consistent with Girardi *et al.* (2007), who reported that Volkamer Lemon exhibits greater growth under

Table 4. Plant height and stem diameter of three citrus rootstocks grown in four substrates with different ratios of pine bark under nursery conditions.

Rootstock	Plant height (cm)	Stem diameter (mm)
Volkamer Lemon	118.05 a	7.8 b
Citrange C-35	108.56 b	8.2 a
Sour Orange	79.69 c	6.8 c
HMSD	4.28	0.23

*Means with different letters in each column indicate significant statistical differences (Tukey, $p \leq 0.05$). HMSD: honest minimum significant difference. $n = 20$.

nursery conditions. Volkamer Lemon showed greater plant height than C-35, which was superior to Sour Orange. Regarding stem diameter, C-35 surpassed Volkamer Lemon, superior to Sour orange (Table 4). According to Albrecht *et al.* (2020), C-35 and Volkamer Lemon reach the recommended stem diameter for grafting (5 to 6 mm) faster. This may be due to the higher number of stomata in both varieties (data not shown), which promotes photosynthesis (Xiong and Flexas, 2020).

Between months two and three, the three rootstocks displayed a significant increase in height (Figure 1). There was no significant effect on the four substrates during the rootstock development process. However, in substrate 4, Volkamer Lemon (124.1 cm for plant height and 7.9 mm for stem diameter) and Citrange C-35 (110.5 cm for plant height and 8.4 mm for stem diameter) exhibited the most growth. In substrate 1, Sour Orange showed the least growth, with a plant height of 84.5 cm and a stem diameter of 6.9 mm (Figures 1 and 2). Meanwhile, Volkamer Lemon displayed the most growth and consistent development throughout the evaluation period.

The growth dynamics of the tested rootstocks were similar to those of the 'Cravo' rootstock when grown in a pine bark-based substrate (de Almeida *et al.*, 2012). However, they were not similar to the Swingle Citrumelo, which exhibited the most growth during months four and five after transplanting (Sauer-Liberato *et al.*, 2021). The three rootstocks grown in all substrates reached the recommended diameter for grafting (5 to 6 mm) four months after transplanting, as previously indicated (Albrecht *et al.*, 2020). Transplanting is one of the most challenging stages in a nursery, as the roots are not fully functional in the first few weeks; the substrate plays a crucial role in preventing water stress. Among the citrus varieties evaluated, Volkamer Lemon and C-35 exhibited the most growth, reaching the suggested diameter for grafting in a shorter time than Sour Orange. This could reduce production costs.

Arrieta-Ramos *et al.* (2014) conducted a study on the effect of root malformation on the growth of Citrange Carrizo, Swingle Citrumelo (C.P.B. 4475), and Volkamer Lemon in an open environment. The substrate used was a mixture of river valley soil, vermicompost, and agrolite in a 3:1:1 ratio (v:v:v). At the time of transplanting, the plants were four months old. Height and stem diameter were evaluated when the plants were 10 months old. Volkamer Lemon reached a height of 86 cm and a stem

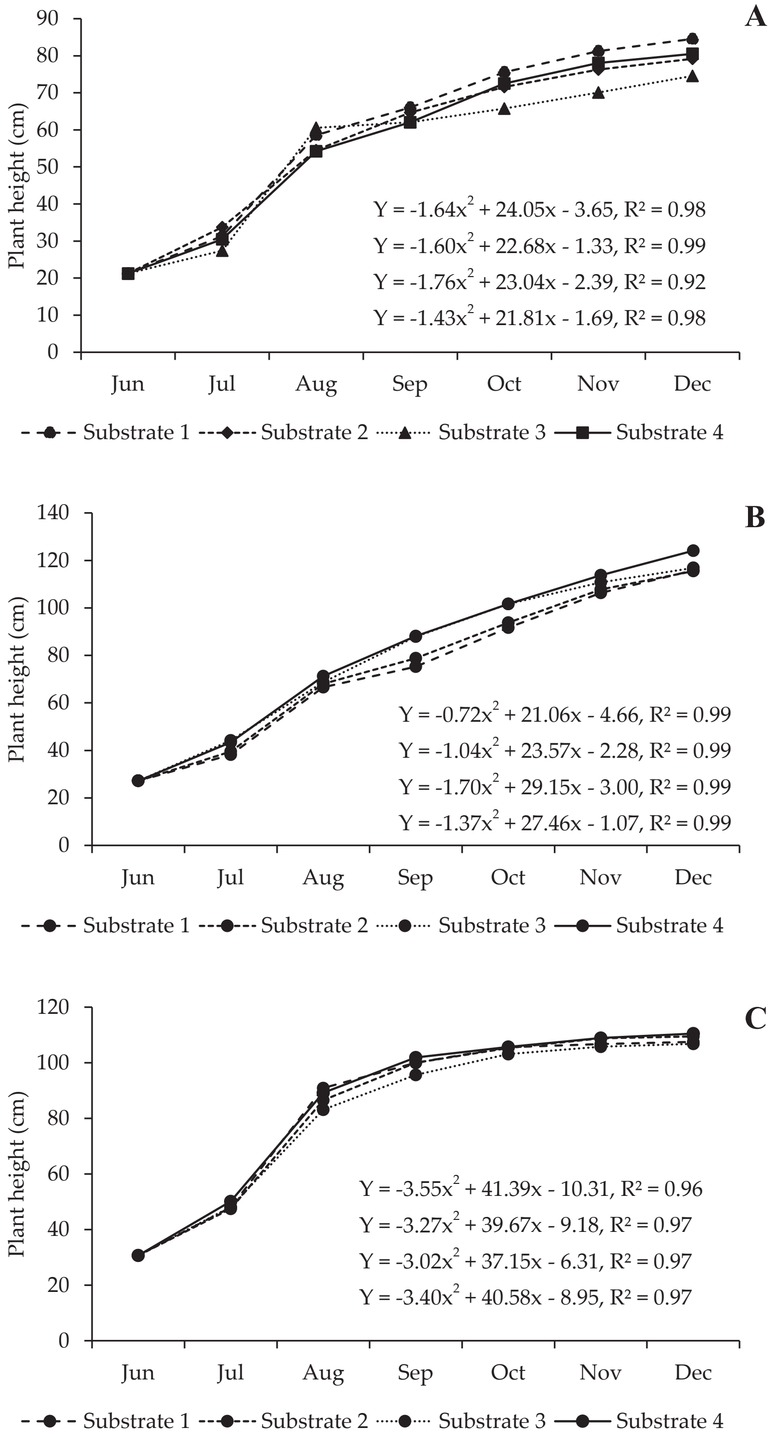

Figure 1. Growth changes of citrus plants grown in four substrates with different ratios of pine bark under nursery conditions. A: Sour Orange; B: Volkamer Lemon; C: Citrange C-35. Substrate 1: control, RV:Tz, 3:1 (v:v); Substrate 2: C:CP, 9:1 (v:v); Substrate 3: C:CP, 8:2 (v:v); Substrate 4: C:CP, 7:3 (v:v). RV: river valley soil; Tz: tepetzil; PB: pine bark. *n* = 20.

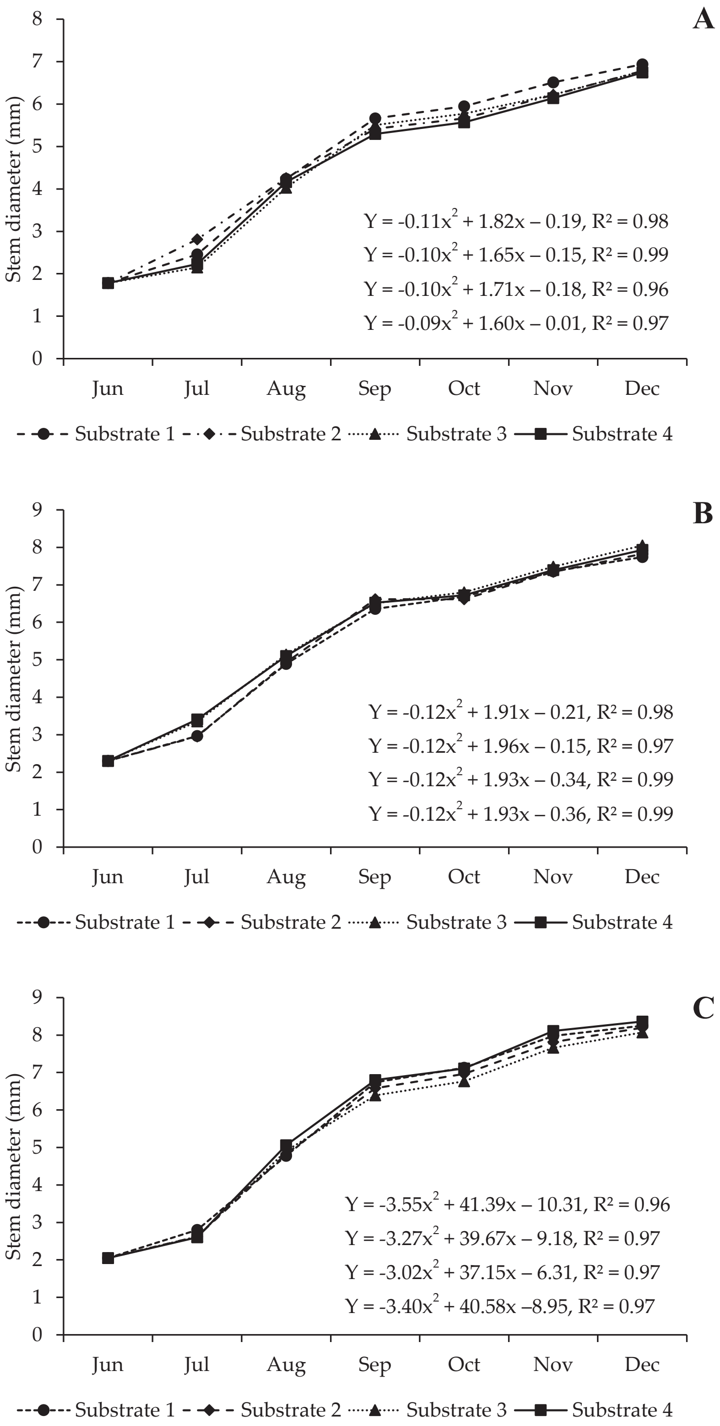

Figure 2. Stem diameter changes of citrus plants grown in four substrates with different ratios of pine bark under nursery conditions A: Sour Orange; B: Volkamer Lemon; C: Citrange C-35. Substrate 1: control, RV:Tz, 3:1 (v:v); Substrate 2: C:CP, 9:1 (v:v); Substrate 3: C:CP, 8:2 (v:v); Substrate 4: C:CP, 7:3 (v:v). RV: river valley soil; Tz: tepetzil; PB: pine bark. *n* = 20.

diameter of 7.5 mm. In our study, six months after transplanting, Volkamer Lemon reached a height of 124 cm and a diameter of 7.9 mm. This indicates that the plants obtained were suitable for grafting four months prior. The results demonstrate the significance of substrate effects, management, and environmental conditions on plants grown in greenhouse environments.

Arce and Rivera (2018) evaluated the effect of substrates and fertilizer on Citrange Carrizo and Citrumelo Swingle rootstocks. They used five substrates for their growth: 1) Promix and sand in a 1:1 ratio (v:v) (control); 2) Promix + sand + coconut fiber; 3) Promix + sand + coffee compost; and 4) Promix + sand + rice husk. The latter three substrates were in a 1:1:1 ratio (v:v:v). After six months, the 'Swingle' plants ranged from 31.1 to 49 cm and had a stem diameter of 3 to 4.25 mm, while Carrizo reached a plant height between 40.3 and 66.7 cm and stem diameters between 2.66 and 4 mm. These results are lower than those reported here. The substrate composed of rice husk had a negative influence on the growth of both rootstocks. 'Carrizo' showed the best development in substrate 3, while 'Swingle' did not exhibit significant differences in any substrate except for rice husk. This highlights the importance of assessing the physical and chemical characteristics of substrates for each rootstock.

The analysis of plant height (cm) and stem diameter (mm) means in the interaction of the studied factors (Rootstock × Substrate) showed that Volkamer Lemon had greater growth than C-35 and Sour Orange in all substrates, specifically in substrate 4. Conversely, Citrange C-35 in substrate 4 had the greatest stem diameter (Table 5). Sour

Table 5. Plant height (cm) and stem diameter (mm) of three citrus rootstocks for (Rootstock × Substrate) interaction, grown in four substrates with different ratios of pine bark under nursery conditions.

Rootstock × Substrate*	Plant height (cm)	Stem diameter (mm)
VL in S1	115.8 ab	7.7 b
VL in S2	115.5 ab	7.8 b
VL in S3	116.9 ab	8.0 b
VL in S4	124.1 a	7.9 b
C-35 in S1	107.5 b	8.3 b
C-35 in S2	109.5 b	8.2 b
C-35 in S3	106.8 b	8.1 b
C-35 in S4	110.5 b	8.4 a
NA in S1	84.5 c	6.9 c
NA in S2	79.2 c	6.8 c
NA in S3	74.6 c	6.8 c
NA in S4	80.5 c	6.7 c
HMSD	12.0	0.65

LV: Volkamer Lemon; C-35: Citrange C-35; AO: Sour Orange; S: substate; RV: river valley soil; Tz: tepetzil; PB: pine bark. *S1: Control, RV:Tz, 3:1 (v:v); S2: C:CP, 9:1 (v:v); S3: C:CP, 8:2 (v:v); S4: C:CP, 7:3 (v:v). Means with different letters in the same column are statistically different (Tukey, $p \leq 0.05$). HMSD: honest minimum significant difference. $n = 20$.

Orange had the least height and stem diameter, regardless of the substrate. Sauer-Liberato *et al.* (2021) found that Swingle Citrumelo (*Citrus paradisi* Macf. × *Poncirus trifoliata* L.) had a plant height of 106.8 cm and a stem diameter of 8 mm after five and a half months of being transplanted into 4 L polyethylene bags. The substrate was composed of varying proportions of peat, vermiculite, and rice husk. Similar results were obtained in this investigation with Volkamer Lemon, which had a plant height of 124 cm and a stem diameter of 7.9 mm six months after transplanting. The observed differences in rootstock height are attributed to the species, as evidenced by the growth dynamics of the three rootstocks (Figures 1 and 2).

CONCLUSIONS

The growth of Volkamer Lemon, Citrange C-35, and Sour Orange trees was enhanced in substrates with 46 to 54 % total porosity. After four months of transplanting, the trees were suitable for grafting. Adding pine bark at 10, 20, and 30 % of the substrate improved its apparent and real physical densities, electrical conductivity, total porosity, and cation exchange capacity. Under nursery conditions, Volkamer Lemon, Citrange C-35, and Sour Orange trees can grow in substrates with pH values ranging from 7.7 to 8.05.

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