Article

Evaluation of substrates, nutrient solution and rooting agent in tomato seedling production

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Abstract

Obtaining high quality vegetable seedlings in seedlings allows producers to reduce the loss of seed, reduce the time to reach the optimum transplant height, minimize the loss of plants in soil or substrate and better adapt to the environment where the final transplant is performed. Producing seedlings in the best substrate and nutrition conditions increases the success of any crop. In most cases, imported substrates are used to produce seedlings in Mexico. For this reason, it is convenient to investigate alternatives of locally available substrates. The objective was to compare four substrates in two concentrations of the Steiner nutrient solution and a rooting agent in tomato seedlings (*Lycopersicum esculentum* Mill.) in the greenhouse. A factorial experiment with 16 repetitions was established in a completely randomized design. The variables were: days to emergence and appearance of the first true leaves, seedling height, stem thickness, number of leaves, fresh and dry weight of biomass and root. The results showed that the substrates that provided the best seedling quality characteristics were peat moss and tezontle, although there were no significant differences between 50% and 100%, to the nutrient solution, the concentration at 100% showed plants with higher quality and the rooting did not show a positive effect on the quality of the seedlings. Based on the above, the tezontle is recommended as a substrate to produce tomato seedlings because it is low cost, with a 100% Steiner nutrient solution, without applying a rooting agent.

Keywords: *Lycopersicum esculentum* Mill., seedling, seedling quality, tezontle.

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Introduction

Vegetable production in Mexico has undergone a transition stage from traditional to technical systems both in greenhouse and open field, now crops with high economic value for the market are produced, such as tomato, a vegetable that is grown intensively in the world, by its levels of demand and consumption. It is an important source of vitamins, minerals, carbohydrates and bioactive compounds, among others ‘lycopene’ as mentioned by Navarro and Periago (2016), beneficial for human health, has a wide range of fresh use and is an important raw material for the transformation industry (Martínez *et al*., 2017).

In our country, the main states in which tomatoes are grown in order of importance are: Sinaloa, San Luis Potosí, Michoacán, Jalisco, Zacatecas, Baja California Sur, Puebla, Morelos, Baja California and Sonora, in addition Mexico has been placed as the 9th producer worldwide and is considered the world leader in the export of this vegetable destined mainly to the United States of America (SIAP, 2019).

Faced with the new technologies applicable to greenhouse crops, farmers have in front of them a very encouraging investment field; that is why the tomato surface under greenhouse conditions has been increasing in recent years (Monge and Loría, 2019). One of the intensive tomato production methods is the sowing of seedlings that come from a seedbed, the efficiency of this system depends, to a great extent, that the seeds germinate and emerge as quickly and the seedlings obtained reach in the least possible time the ideal growth parameters for their subsequent transplantation (Enríquez-Acosta and Reyes-Pérez, 2018), since it is at this stage, where we seek to strengthen their morphology to achieve a successful adaptation after transplantation (Nava-Pérez *et al*., 2019).

The success in the production of seedlings involves several factors, but two of the most important are the substrate or growth medium and nutrition, which is applied to the plant (Gaytán-Ruelas *et al*., 2016). Fundamentally on the quality of the seedling used, the productivity of the crop will depend (Rodríguez *et al*., 2013). The physical-chemical characteristics of the substrates are important for the production of seedlings and affect their growth and development, that is why they must have good properties that make their use possible, and they must also be previously evaluated to identify those that present acceptable characteristics (López *et al*., 2013).

To achieve the appropriate properties in the substrates, organic and inorganic materials must be combined, which are capable of providing adequate physical and nutritional support to produce quality, large-scale seedlings (Pérez *et al*., 2017). In the last two decades, the use of inert commercial substrates has been implemented in the greenhouse tomato production, in most cases substrates are used that have generated technological dependence, high production costs and accelerated depletion of natural resources (Martínez-Rodríguez *et al*., 2017; Nava-Pérez *et al*., 2019).

Another factor to consider in seedling production is nutrition, since it plays a fundamental role at this stage, in transplantation and during crop production, based on this, balanced nutrient solutions can be made and applied for each of the growth, flowering and fruiting stages or fruit filling

(Gaytán-Ruelas *et al*., 2016). Most of the recommended nutritional solutions are obtained by mixing the nutrients in different proportions, subsequently sowing, in this way, the mixture of nutrients with which the best characteristics of the crop are obtained, is the one recommended as a specific nutrient solution for himself (Villegas-Torres *et al*., 2005).

Due to the important role that these two elements play, it is convenient to carry out research to find a suitable substrate with local and easily accessible materials, as well as to recommend the optimal concentration of nutrients for the production of tomato seedlings. In addition, it is important that these investigations generate sustainable techniques for obtaining seedlings of high quality, vigor and adaptability, that is, seedlings with well-developed roots and rapid adaptation to the stress conditions caused by transplantation (Cruz *et al*., 2016).

Based on the above, the objective of this work was to study four substrates, two concentrations of nutrient solution, plus the use of a rooting agent (growth regulator) to obtain tomato seedlings (*Lycopersicum esculentum* Mill.) under protected conditions. The hypothesis is that there are effects on the response in the development of tomato seedlings to different nutritive solutions, substrates and rooting agent.

Materials and methods

Location

The present research work was carried out in module one of a 'Baticenital' greenhouse covered with white plastic with a thickness of 720 gauges and 25% shading. The size is 120 m^2 and it was installed in the Puebla *Campus* of the Postgraduate College, located at 19° 04' north latitude and 98° 15' west longitude, at 2 130 meters above sea level, in the Auxiliary Board of Momoxpan, municipality of San Pedro Cholula, Puebla.

Vegetal material

The plant material used was the saladette-type tomato seed of indeterminate growth variety Santorini from the company ©King Seeds & Cia SA de CV.

Experimental design

The treatment design was a factorial and the experimental design a completely randomized one, with 16 repetitions. The factors under study were the four substrates, two levels of the Steiner nutrient solution and a growth regulator. For them, 200-cavity polystyrene trays were used. The factors were: red tezontle sand, vermicompost, coconut fiber and peat moss, the latter from the Sunshine brand mix 3. The levels of Steiner nutrient solution at 50 and 100% and the rooting agent (growth regulator) Radix 1500 (with and without), a total of 16 treatments. The experimental unit was a seedling in each tray cavity, using one tray per treatment.

Establishment and management of the experiment

Sowing was carried out on June 7, 2018 in 200-cavity polystyrene trays, which were immersed in 3% sodium hypochlorite for 16 h. The substrates were prepared prior to sowing: the red tezontle sand was disinfected with a solution of water and 10% sodium hypochlorite for 19 h, then it was washed and used for sowing, the vermicompost and the coconut fiber where they were moistened with water for 19 h before sowing and the peat moss was moistened with water 15 min before sowing, leaving it at field capacity. This information was obtained from experimental data. Once the trays and substrates were prepared, they proceeded to sowing, for which 20 cavities of each tray were used, which were filled manually with the corresponding substrates. One tomato seed per cavity was sown and deposited 2 mm deep.

When the seedlings emerged, a daily irrigation was applied manually with rainwater, it was until the seedlings presented the appearance of the first true leaves that the application of the nutrient solution began (Steiner, 1968) in concentrations of 50 and 100% for each of the treatments. The amount of fertilizer used to prepare the 100% concentrated nutrient solution was: 6 g of KNO_3, 11 g of $Ca(NO_3)_2$, 3 g of KH_2PO_4, 6.5 g of $MgSO_4$, 6.3 g of K_2SO_4 and 0.8 g of micronutrients Fe, Mn, B, Zn, Cu and Mo. The 50% nutrient solution was prepared equally. As for the rooting agent, Radix (0.15% Indole-3-Butyric Acid) was used as an active ingredient, it was applied when the plant was five days old.

Variables evaluated

The variables evaluated were days to emergency. Days it took at least 50% of the seedlings to emerge. Days to the appearance of the first two true leaves. Time it took for the first true leaves to appear. Seedling height (ALT) (in cm). It was recorded by measuring the base of the stem to the growth point of the last true leaf using a graduated ruler. Stem thickness (DIA) (in mm). The thickness of the stem of the seedlings was measured at the base of the tray, for this a vernier was used. Number of leaves (NH). The number of extended leaflets were counted.

The data of the three previous variables were taken once a week, and with this information, the logistic growth model of Hunt (2017) was also applied. Fresh weight of biomass and root (PFB) (in g). To measure this variable, the root was cleaned and the weight was recorded using a digital scale. Dry weight of biomass and root (PSB) (in g). For this variable, the seedlings were placed in a drying oven at a temperature of 50 °C for 24 h, then the weight was recorded on an analytical balance, these data were obtained from eight repetitions and were recorded at the end of the experiment (44 DDS). Root length and width (LOR and ANR) (in cm). They were measured using a graduated ruler.

Statistical analysis

The analysis of variance and the Tukey mean comparison test ($p \leq 0.05$) were performed using the statistical package Statistical Analysis System version 9 (SAS, 2002).

Logistics models

These models allow to express the growth or development of plant parameters, in such a way that for the variables of this study: plant height (ALT), stem thickness (DIA) and number of leaves (NH), the models were used plant growth logistic presented by Hunt (2017). With the following expression: $Y= A/(1+B*EXP^{(-C*X)})$. Where: Y, is the dependent variable (ALT, DAY or NH); X is the independent variable (DDS, days after sowing); EXP, is the natural or natural logarithm (*e*) = 2.718281828; A, is a parameter that is related to the maximum value of the logistic model curve; B, is a parameter that is related to the ordinate at the origin y; C, is a parameter that is related to the slope of the model at its point of greatest increase. These parameters were calculated with the PROC NLIN program of the Statistical Analysis System of the SAS Institute (SAS, 2002).

Results and discussion

Days to seedling emergence

The results obtained showed that the shortest seedling emergence time occurred with the peat moss substrate (4 days). Under conditions of tezontle sand substrate, the seeds had an emergence time of 6 days. In contrast, with coconut fiber and vermicompost, the seedlings took 9 and 14 days respectively to emerge. The difference in emergence between peat moss and vermicompost was 10 days. In this regard and in a comparative way, Florido *et al*. (2018), comments that, under optimal germination conditions, most tomato seeds emerge in a period of 2 to 5 days.

The beginning of the emergence seems to be related to the physical-chemical characteristics of the substrates, in the case of peat moss, its high retention of moisture and porosity stand out (Fernández-Bravo *et al*., 2006), which allows the seed obtain the best conditions for its emergence in a relatively shorter time, compared to the rest of the substrates, which have less favorable characteristics for germination such as low moisture retention and less porosity (Ortega *et al*., 2016).

Days to the appearance of the first two true leaves

In Figure 1, the days that elapsed from emergence, until the appearance of the first two true leaves in the tomato seedlings, produced in the different substrates evaluated, are shown. Again, the peat moss substrate presented the shortest time in the appearance of the first two true leaves, compared to the rest of the substrates. In general, the coconut fiber and vermicompost substrate took the longest with more than 20 and 30 days to generate the first two true leaves.

In relation, Berrospe-Ochoa *et al*. (2015), report that the first two true leaves in tomato take between 13 and 14 days after sowing, data that coincide with the results obtained in the seedlings that were produced in the peat moss and tezontle substrates (11 and 14 days respectively). The appearance of vegetative organs in seedlings is favored by the use of peat-based substrates (peat moss), since their porosity provides greater aeration, with adequate biological characteristics that facilitate the emission of the number of true leaves (Sarduy and Castellanos, 2011).

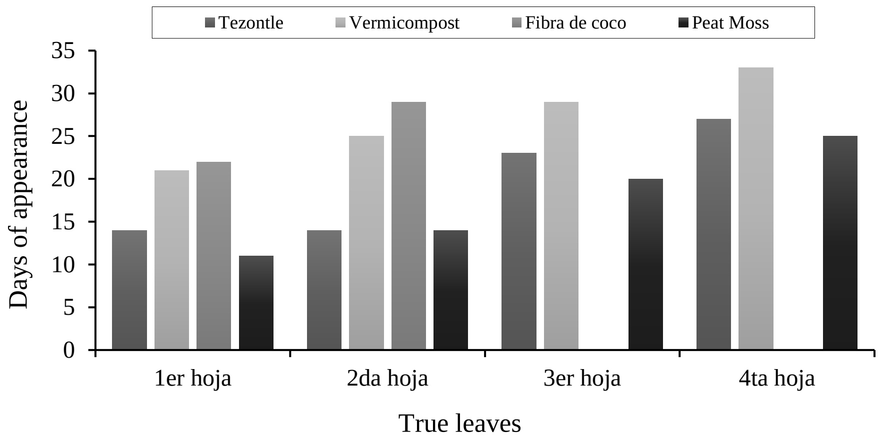

Figure 1. Days of organ appearance in tomato seedlings produced on different substrates.

Analysis of variance and test of means of the study variables

The analysis of variance for the rest of the variables evaluated indicates that there were statistically significant differences (Table 1), the means comparison tests are also presented to identify the outstanding treatments (Table 2 and 3).

Table 1. Statistical significance of the variables evaluated in tomato seedlings produced in different treatments of substrates, nutrient solution and rooting agent.

FV	GL	ALT	DIA	NH	LOR	ANR	PFB	PFR	PSB	PSR
TR	75	78.85*	1.63*	7.07*	2.84*	0.14*	0.21*	0.0049*	11.41*	0.67*
CME	180	0.72	0.02	0.27	0.1	0.01	0.01	0.0003	6.25	0.02
CV		10.19	7.5	13.73	19.09	40.72	29.66	31.68	28.65	12.43

FV= source of variation; GL= degrees of freedom; TR= treatments; CME= error; CV= coefficient of variation in (%); *= statistical significance 0.01 probability; ALT= height; DIA= stem thickness; NH= number of leaves; LOR= root length; ANR= root width; PFB= fresh weight of biomass; PFR= fresh weight of root, PSB: dry weight of biomass; PSR= root dry weight.

Table 2. Comparison of means of the variables: height, stem thickness and number of leaves in tomato seedlings produced on different substrates.

Treatment	Days after sowing			
	15	22	30	36
	Seedling height (cm)			
Tezontle	2.36 b	3.98 b	8.58 b	11.18 b
Vermicompost	0 c	0.25 c	3.54 c	4.64 c
Coconut fiber	0 c	0.25 c	2.47 d	3.12 d
Peat moss	4.18 a	6.4 a	11.64 a	14.48 a
HSD	0.128	0.16	0.332	0.39
CV	17.09	12.86	11.03	10.19

Treatment	Days after sowing			
	15	22	30	36
	Stem thickness (mm)			
Tezontle	-	1.17 b	2.16 b	2.74 a
Vermicompost	-	0 c	1.18 c	1.52 c
Coconut fiber	-	0 c	0.99 d	1.19 d
Peat moss	-	1.7 a	2.33 a	2.64 b
HSD		0.039	0.062	0.07
CV		11.73	8.18	7.49
	No. of leaves			
Tezontle	1.53 b	2.36 b	4.05 a	5.05 a
Vermicompost	0 c	0.25 c	2.03 b	3.27 b
Coconut fiber	0 c	0.05 d	0.95 c	1.77 c
Peat moss	1.94 a	2.92 a	4.14 a	5.08 a
HSD	0.146	0.13	0.216	0.238
CV	36.78	20.3	16.84	13.73

Means with the same letter in the same column are statistically equal (Tukey, $p \leq 0.05$); HSD= honest significant difference; CV= coefficient of variation.

Table 3. Comparison of means of height, stem thickness and number of leaves in tomato seedlings produced in two nutritional solutions Steiner and rooting.

Treatment	Days after sowing			
	15	22	30	36
	Seedling height (cm)			
S50	1.73 a	2.51 c	6.34 b	8.01 b
S100	1.71 ab	2.74 b	6.75 a	8.6 a
S50+E	1.58 bc	2.49 c	6.53 ab	8.34 ab
S100+E	1.52 c	3.13 a	6.61 ab	8.48 a
HSD	0.128	0.16	0.332	0.39
CV	17.09	12.86	11.03	10.19
	Stem thickness (mm)			
S50	-	0.72 a	1.68 a	2.02 a
S100	-	0.73 a	1.71 a	2.04 a
S50+E	-	0.71 a	1.7 a	2.04 a
S100+E	-	0.73 a	1.59 b	1.99 a
HSD		0.04	0.062	0.07
CV		11.73	8.18	7.5

Treatment	Days after sowing			
	15	22	30	36
	No. of leaves			
S50	0.86 a	1.28 b	2.69 b	3.72 a
S100	0.86 a	1.33 b	2.92 a	3.77 a
S50+E	0.86 a	1.39 b	2.78 ab	3.94 a
S100+E	0.89 a	1.58 a	2.78 ab	3.73 a
HSD	0.146	0.13	0.216	0.238
CV	36.78	20.3	16.84	13.73

Means with the same letter in the same column are statistically equal (Tukey, $p \leq 0.05$); HSD= honest significant difference; CV= coefficient of variation. S50= Steiner nutrient solution 50%; S100= 100% Steiner nutrient solution; E= rooter.

Seedling height

This variable was adjusted to the logistic growth model (Table 4) and according to the results obtained from the analysis of variance presented in Table 2, there was a significant effect when any of the concentrations of the Steiner nutrient solution was applied to the evaluated substrates. When analyzing this variable, according to the means comparison test (Table 3), it was obtained that the highest seedling height was presented with treatment 8 (P + S100), with a height of 16.3 cm, followed by treatments 12 (P + S50 + E), 4 (P + S50) and 16 (P + S100 + E), which can be observed in Figure 2. For its part, treatment 13 (T + S100 + E) also presented values favorable for seedling height, since a height of 13.4 cm was recorded. Ortega-Martínez *et al*. (2010) obtained values of 12-17 cm for the height variable in tomato seedlings grown on different substrates, including peat moss (15 cm).

Table 4. Plant height models in each treatment evaluated for the production of tomato seedlings in different substrate, nutrient solution and rooting agent.

Treatment	Models	F Cal
T+S50	$ALT=13.8827/(1+45.7155*EXP^{(-0.1292*DDS)})$	1801.4^{**}
V+S50	$ALT=4.9129/(1+8383(10^{14})*EXP^{(-1.4113*DDS)})$	1549.81^{**}
F+S50	$ALT=3.5813/(1+239(10^{17})*EXP^{(-1.5452*DDS)})$	502.75^{**}
P+S50	$ALT=17.3457/(1+22.9016*EXP^{(-0.1255*DDS)})$	2841.93^{**}
T+S100	$ALT=16.7177/(1+49.9599*EXP^{(-0.1334*DDS)})$	2013.59^{**}
V+S100	$ALT=3.2439/(1+2556(10^{15})*EXP^{(-1.4563*DDS)})$	236.04^{**}
F+S100	$ALT=3.0377/(1+1359(10^{15})*EXP^{(-1.4308*DDS)})$	1228.41^{**}
P+S100	$ALT=20.6071/(1+38.7106*EXP^{(-0.1392*DDS)})$	5509.9^{**}
T+S50+E	$ALT=13.3692/(1+52.1848*EXP^{(-0.1393*DDS)})$	3553^{**}
V+S50+E	$ALT=5.6127/(1+4267(10^{15})*EXP^{(-1.4768*DDS)})$	2200.83^{**}
F+S50+E	$ALT=2.9688/(1+912(10^{16})*EXP^{(-1.507*DDS)})$	355.93^{**}
P+S50+E	$ALT=20.264/(1+29.7054*EXP^{(-0.1225*DDS)})$	3581.16^{**}

Treatment	Models	F Cal
T+S100+E	$ALT=16.4218/(1+87.6106*EXP^{(-0.1668*DDS)})$	1844.27**
V+S100+E	$ALT=5.248/(1+1905.5*EXP^{(-0.2737*DDS)})$	1062.29**
F+S100+E	$ALT=3.2789/(1+342.4*EXP^{(-0.2165*DDS)})$	817.64**
P+S100+E	$ALT=16.0642/(1+29.7354*EXP^{(-0.1325*DDS)})$	3598.02**

F Cal= F calculated; T= tezontle; V= vermicompost; F= coconut fiber; P= peat moss, S50: Steiner nutrient solution 50%; S100= 100% Steiner nutrient solution; E= rooter; ALT= plant height; EXP= natural logarithm (2.7183); DDS= days after sowing; **= probability (<0.01).

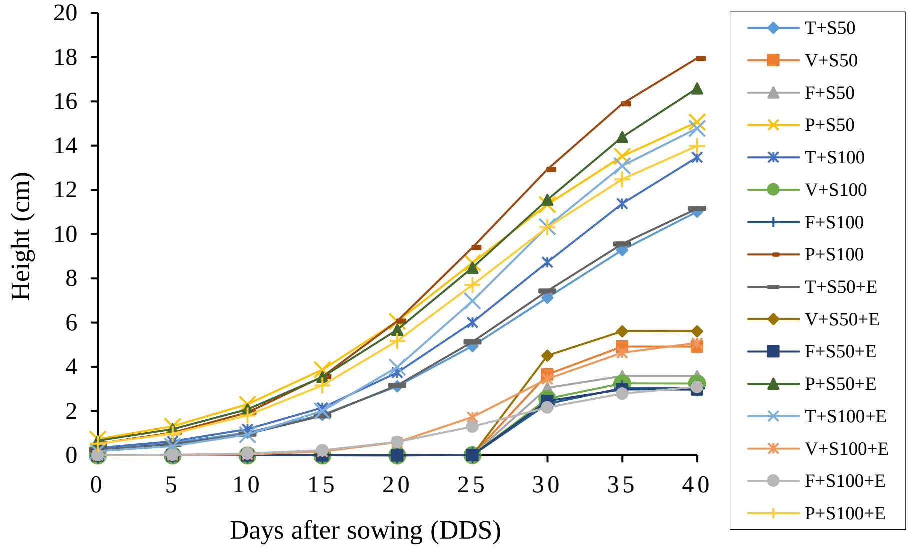

Figure 2. Height of tomato seedlings produced in different treatments of nutrient solution, substrates and rooting. T= tezontle; V= vermicompost; F= coconut fiber; P= peat moss; S50= 50% nutrient solution; S100= 100% nutrient solution; E= rooter.

Regarding the application of rooting agent, there were no significant differences (Table 3); however, regarding the application of the nutritive solution, the seedlings with the best values were those produced in treatment 8 (P + S100). Arebalo-Madrigal *et al.* (2019) report that the use of rooters in the production of tomato seedlings favors the development of important parameters at the time of transplantation, including the height of the seedling. In addition, the development of the seedlings, in their initial stage, is directly related to the uniformity in germination and this, in turn, can be attributed exclusively to the characteristics of the substrate (Fernández-Bravo *et al*., 2006).

Stem thickness

In relation to the thickness of the stem, the test of comparison of means shown in Table 2, indicates that the best values were obtained with the substrate and tezontle. For its part, regarding the application of the nutritive solution and rooting agent (Table 3), there were no significant differences, however, in the last sampling carried out the treatments that showed the highest values were treatment 5 (T+S100) and 13 (T+S100+E), as can be seen in Figure 3, which was adjusted to the logistic growth model presented in Table 5.

Table 5. Stem thickness models of each evaluated treatment, for the production of tomato seedlings in different substrate, nutrient solution and rooting agent.

Treatment	Models	F Cal
T+S50	$DIA=2.6124/(1+1770.1*EXP^{(-0.3223*DDS)})$	2913.73**
V+S50	$DIA=1.6189/(1+6506(10^{14})*EXP^{(-1.401*DDS)})$	2691.04**
F+S50	$DIA=1.1157/(1+7034(10^{15})*EXP^{(-1.4967*DDS)})$	1331.47**
P+S50	$DIA=2.5371/(1+36810264*EXP^{(-0.8263*DDS)})$	3821.44**
T+S100	$DIA=2.916/(1+503.2*EXP^{(-0.2518*DDS)})$	2019.19**
V+S100	$DIA=1.3363/(1+1153(10^{16})*EXP^{(-1.5163*DDS)})$	1739.32**
F+S100	$DIA=1.28/(1+8939(10^{15})*EXP^{(-1.5062*DDS)})$	4259.55**
P+S100	$DIA=2.6071/(1+80714485*EXP^{(-0.8615*DDS)})$	5132.96**
T+S50+E	$DIA=2.6124/(1+1770.1*EXP^{(-0.3223*DDS)})$	2913.73**
V+S50+E	$DIA=1.6314/(1+8263(10^{14})*EXP^{(-1.4107*DDS)})$	2557.01**
F+S50+E	$DIA=1.1594/(1+1928(10^{16})*EXP^{(-1.5367*DDS)})$	2336.78**
P+S50+E	$DIA=2.5427/(1+10031704*EXP^{(-0.7625*DDS)})$	3172.81**
T+S100+E	$DIA=2.9084/(1+267.7*EXP^{(-0.2263*DDS)})$	1327.23**
V+S100+E	$DIA=1.5057/(1+4551(10^{16})*EXP^{(-1.4793*DDS)})$	1250.42**
F+S100+E	$DIA=1.2106/(1+1466(10^{16})*EXP^{(-1.5259*DDS)})$	3762.33**
P+S100+E	$DIA=2.275/(1+99773007*EXP^{(-0.8811*DDS)})$	3466.84**

F Cal= F calculated; T= tezontle; V= vermicompost; F= coconut fiber; P= peat moss, S50: Steiner nutrient solution 50%; S100= 100% Steiner nutrient solution; E= rooter; ALT= plant height; EXP= natural logarithm (2.7183); DDS= days after sowing; **= probability (<0.01).

On average, seedlings with a stem thickness of 2.7 mm were obtained in peat moss and tezontle substrates, while using vermicompost and coconut fiber an average stem thickness of 1.5 and 1.2 mm was obtained, respectively (Figure 3). As can be seen, with these last two substrates a lower quality of the stem is obtained and with it, a lower possibility of success after transplantation.

Stem thickness is an indicator of the vigorous state of a seedling since it directly reflects the accumulation of photosynthates, which can be transferred to demand sites (Parra-Terraza *et al*., 2010). Fernández-Bravo *et al*. (2006), evaluated the emergence of tomato seeds in different substrates (peat moss, compost, coconut sawdust) and obtained values for the variable stem thickness from 0.9 to 1.3 mm.

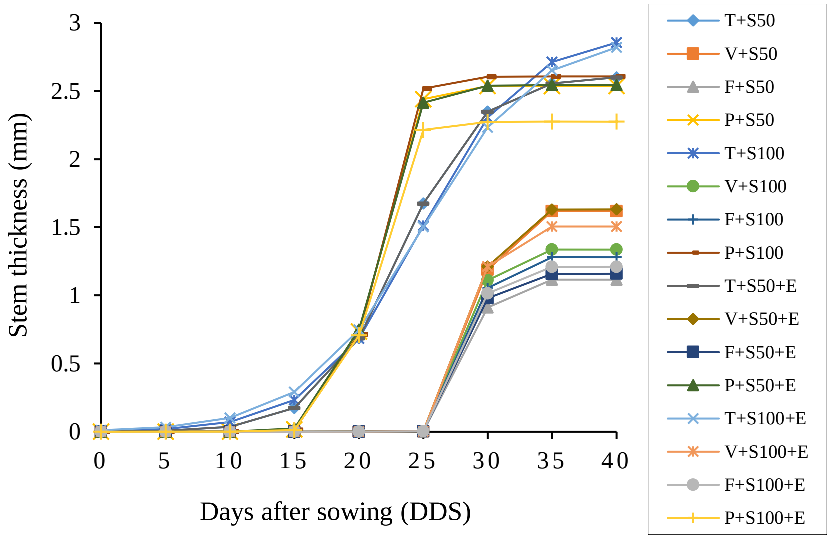

Figure 3. Variation of stem thickness in tomato seedlings produced in different treatments of nutrient solution, substrates and rooting agent. T= tezontle; V= vermicompost; F= coconut fiber; P= peat moss; S50= 50% nutrient solution; S100= 100% nutrient solution; E= rooter.

Number of leaves

This variable was also adjusted to a logistic growth model proposed by Hunt (2017) (Table 6) and, according to the results, there were significant differences between the different substrates evaluated; as can be seen, the seedlings that presented more leaves were those that were sown in peat moss and tezontle, highlighting treatments 5 (T + 100) and 8 (P + S100) in which an average of 5 leaves per seedling were counted, on the other hand, the substrates based on vermicompost and coconut fiber showed the lowest values, 3 and 2 leaves respectively, this also due to the fact that in these substrates the seedlings took longer to emerge (Figure 4).

Table 6. Models related to the number of leaves of tomato seedlings in the evaluated treatments.

Treatment	Models	F Cal
T+S50	$NH=6.4617/(1+28.2191*EXP^{(-0.1259*DDS)})$	1410.01^{**}
V+S50	$NH=3.5012/(1+3684(10^{13})*EXP^{(-1.2811*DDS)})$	1112.22^{**}
F+S50	$NH=1.6693/(1+2254(10^{5})*EXP^{(-0.6344*DDS)})$	89.17^{**}
P+S50	$NH=5.0438/(1+17.7134*EXP^{(-0.1493*DDS)})$	3259.93^{**}
T+S100	$NH=6.7075/(1+31.8663*EXP^{(-0.1318*DDS)})$	1478.71^{**}
V+S100	$NH=2.4378/(1+2682(10^{14})*EXP^{(-1.3647*DDS)})$	122.87^{**}
F+S100	$NH=2.0005/(1+8106(10^{13})*EXP^{(-1.1314*DDS)})$	456.87^{**}
P+S100	$NH=6.0158/(1+19.7625*EXP^{(-0.1392*DDS)})$	2368.42^{**}

Treatment	Models	F Cal
T+S50+E	$NH=5.7621/(1+22.6797*EXP^{(-0.1334*DDS)})$	1298.73**
V+S50+E	$NH=3.876/(1+6709(10^{13})*EXP^{(-1.3068*DDS)})$	1542.33**
F+S50+E	$NH=1.8667/(1+2001(10^{5})*EXP^{(-0.6285*DDS)})$	125.82**
P+S50+E	$NH=5.7608/(1+17.1909*EXP^{(-0.1298*DDS)})$	2539.22**
T+S100+E	$NH=6.4439/(1+23.7018*EXP^{(-0.1235*DDS)})$	1700.66**
V+S100+E	$NH=4.2718/(1+255.2*EXP^{(-0.1851*DDS)})$	549.1**
F+S100+E	$NH=1.8555/(1+6615.4*EXP^{(-0.2985*DDS)})$	93.18**
P+S100+E	$NH=5.7688/(1+16.3545*EXP^{(-0.1251*DDS)})$	2577.56**

F Cal= F calculated; T= tezontle; V= vermicompost; F= coconut fiber; P= peat moss, S50: Steiner nutrient solution 50%; S100= 100% Steiner nutrient solution; E= rooter; NH= number of leaves, EXP= natural logarithm; (2.7183); DDS= days after sowing; **= probability (<0.01).

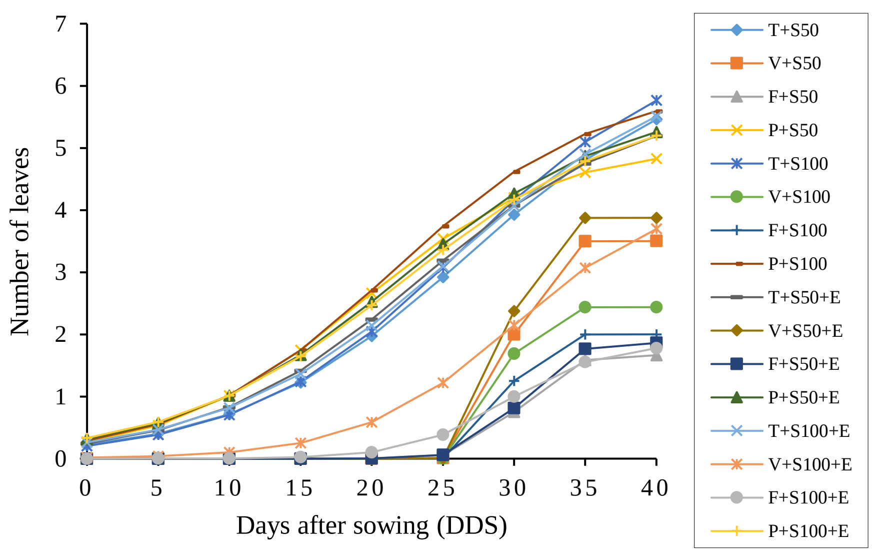

Figure 4. Number of leaves in tomato seedlings produced in different treatments of nutrient solution, substrates and rooting agent. T= tezontle; V= vermicompost; F= coconut fiber; P= peat moss; S50= 50% nutrient solution; S100= 100% nutrient solution; E= rooter.

Parra-Terraza *et al*. (2010) mention that the number of leaves is a valuable indicator in terms of the quality of the seedlings, and that in the case of tomato, the seedlings must present 6 to 7 leaves at the time of transplantation. Regarding the nutrient solution applied, there were no significant differences (Table 3); however, the number of leaves was favored when applying the 100% nutrient solution (Figure 4). Nitrogen is a structural part of the chlorophyll molecule and is the main component of essential proteins for the formation of protoplasm, a higher plant height leads to an increase in the number of leaves, influencing an increase in photosynthesis (Espinosa-Palomeque *et al*., 2019).

Root length and width

The response in growth of the main root length did not have a significant effect for the evaluated treatments (Table 7); however, the longest root length was obtained in the plants in the treatments that applied rooting and the concentration of the nutrient solution to 100%. Arebalo-Madrigal *et al*. (2019) evaluated the use of rooters in tomato seedlings and indicate that these favor the number of roots, root exploration area and root length.

The root width showed the opposite since the highest values were obtained in the treatments where no rooting agent was used and with the 50% concentrated nutrient solution (Table 7). Nava-Pérez *et al*. (2019) mention that the longest root length in tomato seedlings was observed when irrigation included higher concentrations of phosphorus; however, roots with smaller size were presented with a concentrated nitrogen solution, a similar trend may have occurred when evaluating this variable (Table 7). Although there were no significant differences due to the use of substrates, the tezontle and peat moss showed the best results and as mentioned by Fraile-Robayo *et al*. (2012), this can be attributed to the fact that the germination stage time is very short and the treatments fail to show a significant effect on these variables.

Table 7. Comparison of means of root length and width, fresh and dry weight of biomass and root, in tomato seedlings produced in different substrates, two concentrations of nutrient solution and rooting agent.

Factor	LOR	ANR	PFB	PFR	PSB	PSR
	(cm)	(cm)	(g)	(g)	(g)	(g)
Solution and rooter						
S50	7.62 b	1.278 a	1.687 a	0.404 a	0.27 a	0.068 a
S100	8.37 ab	1.019 c	1.696 a	0.357 ab	0.261 a	0.052 b
S50+E	9.2 ab	1.172 b	1.679 a	0.404 a	0.235 a	0.058 ab
S100+E	9.71 a	1.088 b	1.499 a	0.297 b	0.223 a	0.047 b
HSD	1.638	0.093	0.205	0.071	0.066	0.012
CV	28.647	12.432	19.09	29.66	40.72	31.68
Substratum						
Tezontle	8.997 a	1.566 a	2.277 b	0.499 b	0.365 b	0.094 a
Vermicompost	7.944 a	0.947 b	1.151 c	0.187 c	0.1 c	0.027 b
Coconut fiber	8.9 a	0.566 c	0.427 d	0.106 d	0.034 c	0.014 c
Peat moss	9.053 a	1.478 a	2.706 a	0.671 a	0.489 a	0.09 a
HSD	1.638	0.093	0.205	0.071	0.066	0.012
CV	28.65	12.43	19.09	29.66	40.72	31.68

Means with the same letter in the same column are statistically equal (Tukey, $p \leq 0.05$); HSD= honest significant difference; CV= coefficient of variation; LOR= root length; ANR= root width; PFB= fresh weight of biomass; PFR= fresh weight of root; PSB= dry weight of biomass; PSR= root dry weight; S50= Steiner nutrient solution 50%; S100= 100% Steiner nutrient solution, E= rooting.

Dry weight of biomass and root

For the variable of dry weight of biomass and dry weight of root, there were no significant differences due to the concentration of the nutritive solution (Table 7). On the other hand, when evaluating substrates, there were significant differences. The substrates that produced the highest values were peat moss and tezontle, with values of 0.49 g and 0.37 g respectively. In relation to the dry weight of the root, with the same substrates, a weight of 0.09 g was obtained. The seedlings that were produced in presented the lowest values for this variable of 0.03 and 0.01 g. The vermicompost and coconut fiber substrates show some type of physical or chemical deficiency that affects the development of the seedlings (Cruz-Crespo *et al*., 2013).

Conclusions

Of the substrates studied in this work, peat moss (P) and tezontle sand (T) were the ones that presented the best results in all the variables evaluated and quality characteristics of the seedling, and with it, tezontle sand represents a viable alternative for the production of tomato seedlings in trays and greenhouse, considering the local availability. The evaluation of the two levels of Steiner nutrient solution did not show significant differences regarding the quality of seedlings in trays, despite this, the highest values of the variables were obtained with the concentration at 100%, this opens the possibility of use both concentrations. The application of rooting agent (E) in half of the treatments studied did not have a significant effect on the quality variables of the seedling produced, therefore, it is inconsequential to apply this product.

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