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Article

Rooted cuttings, an alternative for tomato production under greenhouse in short cycles

Francisca de los Ángeles Mejía-Betancourt[1]
Felipe Sánchez Del Castillo[2]
Esaú del Carmen Moreno-Pérez[2§]
Lucila González-Molina[3]

[1]National Agrarian University. North highway-Managua km 12.5, Managua, Nicaragua. CP. 453. Tel. 505 22331853, ext. 5225. (franciscabetancourt@hotmail.com). [2]Chapingo Autonomous University. Mexico-Texcoco highway km 38.5, Texcoco, State of Mexico, Mexico. CP. 56230. Tel. 59 9521500, ext. 6313. (fsanchezdelcastillo@yahoo.com.mx). [3]Valley of Mexico Experimental Field-INIFAP. Los Reyes-Texcoco highway km 13.5, Coatlinchán, Texcoco, State of Mexico, Mexico. CP. 56250. (gonzalez.lucila@inifap.gob.mx).

[§]Corresponding author: esaump10@yahoo.com.mx.

Abstract

Tomato (*Solanum lycopersicum* L.) under greenhouse conditions, managed in high population densities and short cycles, allows obtaining yields of up to 500 t ha^{-1} $year^{-1}$; however, with this form of management, high quantities of seedlings that come from hybrid seed, which is very expensive, are occupied. An alternative that is perceived as economically more viable is the obtaining of seedlings from rooted cuttings, so the objective of this study was to evaluate the growth and yield of tomato plants from cuttings and seeds. Six ages of transplantation of cuttings [20, 25, 30, 35, 40 and 45 days after the start of rooting (dasr)] and one age of seed [45 days after sowing (das)], as a control, were tested. An experimental design of randomized complete blocks with four repetitions and ten seedlings per experimental unit was used. Analysis of variance and comparison of means (Tukey, $p \leq 0.05$) were performed. Seedlings from cuttings transplanted earlier had higher vegetative growth than those from seed, but in yield there were no differences. With plants from cuttings, the average yield was 14.5 kg m^{-2} and it can be obtained in a period of 90 days from transplantation to the end of harvest, which makes it possible to obtain four cultivation cycles per year. It is concluded that seedlings obtained from rooted cuttings constitute a viable option for the management of the crop in high population densities.

Keywords: *Solanum lycopersicum* L., botanical seed, rooted cuttings.

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Introduction

Tomato (*Solanum lycopersicum* L.) is a vegetable of great importance nationally and worldwide due to its wide consumption, harvested area and economic value, in addition to the social contribution it has since it generates a high number of direct and indirect jobs due to the abundant labor that its management requires, especially under greenhouse conditions (Contreras *et al*., 2013; Sánchez and Moreno, 2017; SIAP, 2021). The demand for its fruits increases every day, and with it the need to increase its productivity (Sosa and Ruíz, 2017).

In Mexico, tomato production grew at an average annual rate of 3.6% between 2007 and 2017, with a maximum production of 3.47 million tons. In this period, the area cultivated in the open field decreased from 64 663 to 35 175 ha, while that established with greenhouses and shade-houses went from 1 973 to 15 198 ha (FIRA, 2017).

The management of tomato under greenhouse that is practiced by large companies in Mexico and in other countries, such as Holland and Canada, consists of establishing the crop at population densities of 2.5 to 3 plants m^{-2} of greenhouse, using varieties of indeterminate growth habit (Sánchez *et al*., 2012 a). Thanks to the control of the environmental conditions that can be obtained with highly technified greenhouses, at least 20 bunches per plant are harvested in a cultivation cycle that takes up almost the entire year, with yields that exceed 500 t ha^{-1} $year^{-1}$ (Cheiri *et al*., 2018; Heuvelink *et al*., 2018), although with very high production costs, since they also use sophisticated hydroponic systems, which are also expensive (Urrestarazu, 2004).

Most greenhouse tomato producers in Mexico have less than half a hectare and use a lower technological level, so there is little control of microclimatic conditions, as well as of pests and diseases when managing such long cultivation cycles (up to 11 months from transplantation to the end of harvest), yields hardly exceed 300 t ha^{-1} $year^{-1}$ (Castellanos and Borbón, 2009; Sánchez and Moreno, 2017) and with it low economic profitability.

At the Chapingo Autonomous University (UACH, for its acronym in Spanish), an alternative tomato production system under greenhouse and hydroponic conditions has been developed, which is more suitable for small and medium producers and consists of delaying transplantation up to 45 d after sowing and tipping the apex of the plants above the third inflorescence to shorten the cultivation cycle from transplantation to the end of the harvest to approximately 100-110 days, as only three bunches of each plant are harvested.

The system is complemented by the management of plants in high population densities (8 plants m^{-2} of greenhouse) to compensate for the lower yield per plant in relation to the conventional system of a single cycle per year and densities of 2.5 to 3 plants m^{-2} (Sánchez *et al*., 2006; Sánchez *et al*., 2010; Sánchez *et al*., 2012a; Sánchez *et al*., 2014; Moreno *et al*., 2021). The high population density established is possible because each plant produces a smaller leaf area as it is tipped two leaves above the third bunch. By reducing the cultivation cycle, the problems indicated are reduced and the harvest is concentrated in only about 30 days, which allows it to be programmed in windows of better price for greater economic benefit to the producer (Sánchez *et al*., 2014).

With the alternative system of short cultivation cycles indicated, due to the delay of transplantation and the early tipping of plants, three cultivation cycles per year can be obtained, reaching yields close to 500 t ha^{-1} $year^{-1}$ (Sánchez *et al*., 2012a; Moreno *et al*., 2021), with simple greenhouses and a technological level available to most producers in the country.

As it is a very intensive production system with a high population density, a high number of seedlings is required (approximately 240 000 per hectare per year when three cycles are established), usually formed from imported hybrid seed that has a very high unit price, which increases operating costs and although higher annual yields are obtained, the economic profitability of the producer is limited (Sánchez *et al*., 2017; Moreno *et al*., 2021).

In 2022, a single hybrid seed cost on average between four and six pesos, which, for the production system, means an annual cost of at least one million pesos per hectare per year, just for that concept. An alternative to obtain low-cost seedlings with a quality similar to those from hybrid seeds is the rooting of lateral or terminal shoots (cuttings) that are normally discarded during the management practices of the crop and whose rooting is relatively easy and inexpensive (Moreno *et al*., 2016).

However, to confirm this advantage, it is necessary to evaluate whether the yield achieved with plants from cuttings does not decrease compared to that of plants that come from seed. On the other hand, the productivity of the production system of short cycles and high population densities depends on the yield achieved per cultivation cycle and the number of cultivation cycles that can be obtained per year by prolonging the age at late transplantation and tipping only to the third bunch (Sánchez *et al*., 2014; Sánchez *et al*., 2017).

Therefore, it is sought to increase the number of cycles per year to four, maintaining the same productivity per cycle (Sánchez *et al*., 2010), which may be possible through strategies that allow the reduction of the time from transplantation to the end of harvest, such as using older seedlings at the time of transplantation (Juárez *et al*., 2000; Sánchez *et al*., 2014; Sánchez *et al*., 2021), an aspect that has not yet been fully studied. Therefore, for the management of plants from cuttings tipped to three bunches, this work evaluates the possibility of shortening the time from transplantation to the end of harvest to 90 days by lengthening the age at transplantation, in order to make it possible to obtain four cycles per year instead of the three that are achieved with this system from plants from seed and thus increase the annual potential productivity by 25%.

Based on the above, in this research the following main objectives were proposed: to compare the growth and yield of tomato plants from rooted cuttings at different transplantation ages with each other and against that of plants from seed. To define until what age it is possible to delay transplantation using rooted cuttings to shorten the period from transplantation to the end of harvest, without negatively affecting the final yield compared to that of plants from seed.

Materials and methods

Experiment location and plant material

The study was carried out from July to December 2019 in a greenhouse of 300 m^2, located in the experimental agricultural field of the Chapingo Autonomous University, in the municipality of Texcoco de Mora, State of Mexico, with geographical coordinates of 19º 29’ 35.03” north latitude and 98º 52’ 19.86” west longitude, at 2 250 m altitude. The tomato hybrid used was Pai pai from EnzaZaden, with characteristics of saladette-like fruit and indeterminate growth habit.

Obtaining and production of cuttings

To obtain the cuttings, seeds were first sown in trays of 200 cavities, using as a sowing substrate a mixture of plant peat (peat-moss brand) and perlite in a proportion 1:1 (v:v). The first eight days after sowing (das), the seedlings were irrigated with plain water; later and until the moment of transplantation (30 das), the irrigation was carried out with a nutrient solution that contained the following concentrations (mg L^{-1}): N= 100, P= 25, K= 125, Ca= 125, S= 75, Mg= 25, Fe= 1, Mn= 0.1, Cu= 0.1, Mn= 1, B= 0.5 and Zn= 0.1. The following were used as fertilizer sources: calcium nitrate, 85% phosphoric acid, potassium sulfate, magnesium sulfate, ferrous sulfate, manganese sulfate, copper sulfate, boric acid and zinc sulfate.

The transplantation was done in cultivation beds, which were filled with a 25 cm thick layer of red tezontle, whose particles had a diameter of 3 to 5 mm, placing a drip irrigation system by means of tapes with integrated dripper every 20 cm and using a nutrient solution with twice the concentration (100% solution) of that used in the seedling stage. These plants (mother plants) were established only for the purpose of having lateral shoots that would be rooted for later evaluation.

Seventy days after transplantation, the lateral shoots of approximately 15 cm in length with two or three well-formed leaves were collected for rooting, making a diagonal cut for a larger rooting area. Days before cutting and rooting cuttings, a tunnel 10 m long, 3 m wide and 2.5 m high was built, using metal structure (PTR), 11-gauge galvanized wire and agribon fabric as cover.

Low pressure nebulizers were placed throughout the tunnel every 1.3 m to maintain an environment of high relative humidity and avoid dehydration of shoots. The interior of the tunnel was disinfected with Quatz$^{M®}$, which is made from 5% quaternary ammonium salts. Fifty cm above the agribon fabric, a shade mesh (50%) was also placed to maintain a low light intensity (500-1 000 foot-candle) and temperatures of 15-20 °C.

The rooting of shoots was done in polystyrene trays of 60 cavities using only 30 cavities (200 cm^3 volume per cavity) filled with a mixture of plant peat and perlite in a proportion 1:1 (v:v), all this at a density of 150 seedlings m^{-2}. Immediately afterwards, irrigation started using microsprinkling, providing an irrigation of one minute every hour. The water for the microsprinkling contained mineral nutrients (nutrient solution) at the same concentration with which the seedlings to generate the cuttings were irrigated. The sowing for obtaining seedlings from seed (control treatment) was also done in polystyrene trays of 60 cavities, filled with a mixture of plant peat and perlite in equal proportion and at the same population density with which the cuttings were established. The seeds were deposited at a depth of 1 cm, then the trays with substrate were irrigated profusely and stacked for three days for a more uniform germination. After the three days, the trays were extended to prevent the emergence from occurring without light, which causes etiolation of the seedling.

Conduction from transplantation to harvest

The transplantation of both the seedlings from cuttings and seedlings from seed was carried out in cultivation beds one meter wide by 20 m long filled with substrate based on red tezontle sand with particles of 1 to 3 mm in diameter. The crop was established in three rows of plants per bed with distances of 30 cm between rows and 30 cm between plants (7 plants m^{-2} of greenhouse) leaving corridors 50 cm wide between adjacent beds. Rooted cuttings were transplanted at 20, 25, 30, 35, 40 and 45 days after the start of rooting (dasr) and seedlings from seeds at 45 days after sowing (das).

Immediately after transplantation, the plants were tutored by holding them by the stem with a plastic ring supported by a raffia thread tied to wires placed along the beds at a height of 1.5 m. The irrigation was done with a nutrient solution at 100% concentration. When the plants had formed two leaves above the third bunch, the tipping (removal of the main apex of each plant) was performed, to harvest only three bunches per plant.

Basal leaves were also pruned to cause greater ventilation in the lower part of the canopy of the plants and lateral shoots were pruned to drive the plants to a single stem. The shoots were removed as they appeared and before they exceeded 5 cm in length. The harvest was done manually in five cuts that were added to obtain the number of fruits and total yield. By closing and opening side and zenithal windows, we tried to maintain a temperature between 20 and 30 °C and relative humidity between 60 and 80% inside the greenhouse. There was no significant presence of pests or diseases, so no agrochemical applications were required during the production cycle.

Treatments and experimental design

The experimental design used was one of completely randomized blocks, with seven treatments that resulted from six different ages at transplantation of plants from cuttings (20, 25, 30, 35, 40 and 45 dasr) and a control of plants from seed transplanted at 45 das. Four repetitions with experimental units of 10 seedlings were used. The data obtained were subjected to analysis of variance and Tukey's comparison of means ($p \leq 0.05$), using the Statistical Analysis System for Windows 9.0 (SAS, 2002).

Variables evaluated

At the beginning of the harvest (100 days after the rooting of the cuttings began), the following variables were measured: plant height (cm), from the base of the stem to the growth apex, with the support of a tape measure. Stem diameter (mm), between the second and third leaf, with an electronic vernier. Plant width (cm), in the middle part of the plant without spreading the leaves. Leaf area index (m^2 leaf area measured only on the abaxial side/m^2 of covered area), with a LI-3000A leaf area integrator (LI-COR, Inc. Lincoln, NE).

At the end of the harvest that was carried out, the following were also determined: the number of flowers and fruits per plant, the average weight per fruit (g), the yield (g $plant^{-1}$) and the time elapsed from transplantation to the end of harvest (d).

Results and discussion

Morphological variables

The analyses of variance (Table 1) indicate that, statistically, there were significant differences for stem diameter, plant width and leaf area index, but not for plant height.

Table 1. Mean squares of morphological variables and days to anthesis evaluated 100 days after the start of the rooting of cuttings or the sowing of seeds of tomato variety Pai pai.

SV	DF	Height	Stem diameter	Leaf area index	Plant width
Block	3	8.14	1.11	0.42	15.39
Treatment	9	86.92 ns	9.44^{**}	3.85^{**}	29.94^{**}
Error	27	47.08	0.83	0.52	6.26
CV%		7.14	7.3	21.65	6.92
Mean		96 cm	12 mm	3.3 ($m\ m^{-2}$)	36 (cm)

SV= source of variation; DF= degrees of freedom; CV= coefficient of variation; **= highly significant at a $p \leq 0.05$. ns= not significant.

The comparisons of means between treatments (Table 2), show that as the transplantation was delayed until 40 and 45 dasr, three of the four morphological variables studied significantly decreased their expression: stem diameter, width (diameter occupied by each plant) and leaf area per plant reflected in the leaf area index (LAI), with statistical differences between 45-day cuttings compared to 20-day cuttings. Although plant height did not show significant differences, a trend of greater elongation was observed in those plants where transplantation was delayed the most. Between plants from cuttings transplanted 45 days after rooting and plants formed from seed, in none of the morphological variables studied there were significant differences.

Table 2. Comparison of means of morphological variables evaluated 100 days after the start of the rooting of cuttings or the sowing of seeds of tomato variety Pai pai.

Treatment (age of seedlings at transplantation)	Height (cm)	Stem diameter (mm)	Leaf area index ($m\ m^{-2}$)	Plant width (cm)
Cutting 20 days	96.9 a	15 a	4.6 a	39.4 a
Cutting 25 days	95.3 a	13.5 ab	4.2 ab	36.8 ab
Cutting 30 days	89.8 a	12.2 bc	3.4 ab	37.3 ab
Cutting 35 days	90.6 a	13.1 ab	3.6 ab	39.2 a
Cutting 40 days	101.7 a	11.7 bc	2.9 bc	34 ab
Cutting 45 days	101.2 a	11.5 bc	2.5 bc	33.8 ab
Seed 45 days	97 a	10.3 c	1.8 c	32.5 b
LSD	16	2.13	1.68	5.85

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.

The plants transplanted at 20 dasr grew for a shorter time in the restrictive conditions imposed by the seedbed (low container volume for root growth and high population density) and therefore, a longer time in the cultivation beds in an environment with fewer limitations for both the aerial part (less competition for light between plants) and the root (greater volume of substrate), which surely favored their subsequent growth, as has been reported by other authors (Hernández and Kubota, 2016; Sánchez *et al*., 2021).

On the other hand, the plants transplanted later were subjected to greater competition for light and in a smaller volume for the growth of the root and with it with more limitations of water, oxygen and nutrients, a situation that was accentuated as the transplantation was performed later, causing greater stress when passing them to their final place (Tadeo and Gómez, 2013; Moreno *et al*., 2021; Sánchez *et al*., 2021). A similar behavior was observed in the plants from seed and that were transplanted at 45 das, since they surely suffered more stress due to the effect of competition for space and light when growing in the trays, since their values of stem diameter, leaf area index and plant width were statistically the lowest (Table 2).

All these results are explained by the fact that at a longer time spent in the trays in the seedbed, prior to transplantation, the competition for light between the seedlings gradually worsens, negatively affecting the production of photoassimilates and producing morphogenetic alterations that directly affect the seedlings and the growth after transplantation (Wien, 1999; Taiz *et al*., 2015). Also, due to the limited volume of the container where the cuttings root, as time passes, the root encounters more space restrictions that limit the supply of oxygen necessary for its expansion, negatively affecting its subsequent growth (Sánchez *et al*., 2021).

Although there were no significant differences between morphological variables of plants from seed with respect to those formed from cuttings, the few differences observed are probably due to the fact that, with plants from cuttings, from the moment of starting rooting, there is already the advantage that there is plant material formed and therefore an advance in growth with respect to seedlings originated from seed (Sánchez *et al*., 2012b; Moreno *et al*., 2016). These results allow us to indicate that, for a tomato production system to three bunches per plant in high population density, such as the one proposed by Sánchez *et al*. (2012a), it is possible to use rooted cuttings instead of seed, without negatively affecting plant growth and development.

Yield and its components

Regarding the yield per plant and its components, both the analysis of variance (Table 3), and that of comparison of means (Table 4), indicate that there were no significant differences between plants from cutting due to delaying transplantation to 45 dasr or any treatment of rooting cuttings with respect to the control of plants from seed transplanted at 45 das, results that coincide with those reported by Moreno *et al*. (2016).

Table 3. Mean squares of variables of yield and its components in plants of tomato cultivar Pai Pai.

SV	DF	No. of flowers per plant	No. of fruits per plant	Average fruit weight (g)	Yield per plant (g)	Days from transplantation to the end of harvest
Block	3	5.4	4.7	13	52875.2	16.6
Treatment	9	3.4 ns	4.1 ns	114.9 ns	142994.9 ns	127.8^{**}
Error	27	1.6	2	79.6	63203.2	4.9
CV%		6.1	7.3	7.9	11.4	2.2
Mean		20.9	19.4	113.5	2205.4	98.9

SV= source of variation; DF= degrees of freedom; CV= coefficient of variation; **= highly significant at a $p\leq 0.01$. NS= not significant.

Table 4. Comparison of means of treatments of variables of yield and its components evaluated in plants of tomato variety Pai Pai from cuttings with different ages at transplantation and from seed.

Treatment (age of seedlings at transplantation)	No. of flowers per plant	No. of fruits per plant	Average fruit weight (g)	Yield per plant (g)	Days from transplantation days to the end of harvest
Cutting 20 days	20. 5 a	20.3 a	125 a	2 526.5 a	106 a
Cutting 25 days	22.3 a	20.5 a	113.5 a	2 324.5 a	104 ab
Cutting 30 days	22.3 a	20.3 a	113.3 a	2 244 a	101 b
Cutting 35 days	20.5 a	19.3 a	112.5 a	2 185.8 a	96 c
Cutting 40 days	20.5 a	19.5 a	111.3 a	2 168 a	95 c
Cutting 45 days	20 a	18.5 a	110.5 a	2 045 a	90 d
Seed 45 days	20.5 a	17.8 a	108.5 a	1 944.3 a	102 ab
LSD	2.9	3.3	20.8	587.4	4.2

Values with the same letter within each column are equal according to Tukey's test at a $p\leq 0.05$; dasr= days after the start of rooting; das= days after sowing. LSD= least significant difference. CV= coefficient of variation.

Only in days from transplantation to the end of harvest, there were significant differences between treatments, finding that in plants from cuttings transplanted at 45 dasr, the harvest ended twelve days earlier compared to plants originated from seed transplanted at the same age, completing their cultivation cycle from transplantation to the end of the harvest in 90 days, this is possible because with propagation by cuttings, precocity in the cultivation cycle is usually achieved (Hartmann *et al*., 2014).

On average, plants from cuttings formed 21 flowers and 19.7 fruits per plant, with an average fruit weight of 114.4 g, which resulted in an average yield of 2 160 g plant^{-1}, corresponding to 14.5 kg m^{-2} of greenhouse, according to the established density (6.7 plants m^{-2}). This is equivalent to 145 t ha^{-1} in a cultivation cycle, so in a production scheme of three cycles per year, 435 t ha^{-1} year^{-1} could potentially be achieved, a yield that is approximately 50% higher than the 300 t ha^{-1} year^{-1} that good tomato producers achieve with the conventional system of an annual cultivation cycle under medium-tech greenhouses in Mexico (Castellanos and Borbón, 2009; Sánchez *et al*., 2012a; Moreno *et al*., 2021). Although the plants originated from seed produced two fruits less per plant and a slight decrease in the average weight of fruit compared to those from cutting, the yield per plant obtained was statistically equal to that of cuttings.

As shown in Table 2, the delay in the transplantation age of rooted cuttings to 45 dasr did cause a decrease in stem diameter, leaf area and leaf area index, but did not significantly affect any of the variables of yield or any of its components, as can be seen in Table 4. On the contrary, the delay in transplantation allowed the cultivation cycle to be shortened to only 90 days, which potentially gives the possibility of obtaining up to four cultivation cycles per year under greenhouse conditions, that is, one more cycle per year, which implies a possible annual increase in yield of 25% compared to the system of three cycles per year already mentioned. This is up to 580 t ha^{-1} year^{-1}, equivalent to the yields reported by Cheiri *et al*. (2018); Heuvelink *et al*. (2018) in high-tech greenhouses and sophisticated hydroponic systems.

Regardless of the above, the fact that the plants can be kept in the seedbed from 20 to 45 days of age gives the producer flexibility for a more efficient management of the greenhouse in terms of cultivation cycles throughout the year, as it gives them room to advance or delay their transplants optimizing their production.

It should also be noted that the fact that plants from cutting yield the same as plants from seed means great savings in production costs with the use of rooted cuttings. For example, in the system of three cycles per year at a population density of 7 plants m^{-2}, about 230 000 seeds per ha per year would be used, considering 90% germination, with a cost greater than $1 000 000.00 (more than the total cost of the labor required throughout the year).

Obtaining two of the three production cycles with cutting would stop the purchase of about 150 000 seeds, which represents a reduction in production costs of approximately $750 000.00 per year per ha, significantly increasing the economic profit of the producer.

Conclusions

When rooted cuttings were transplanted earlier (20 to 30 d after rooting), plants developed more width, more leaf area and greater stem thickness than plants from seed. As the age of transplantation of plants from cuttings was delayed, the expression of morphological variables, such as stem thickness, leaf area and plant width, was decreased, but the yield per plant was not affected.

The delay of the transplantation of plants from cuttings until 45 d after the start of rooting allowed reducing the period from transplantation to the end of harvest from 102 (seed control) to 90 d, which opens the possibility of obtaining up to four cultivation cycles per year instead of the three that the system of three bunches per plant that uses seeds for sowing has as potential. Obtaining tomato seedlings from rooted cuttings is shown as a viable and economically profitable alternative for the management of the crop in high population densities and tipping of the apex of the plants to leave only three bunches.

Cited literature

Castellanos, J. Z. y Borbón, M. C. 2009. Panorama de la horticultura protegida en México. *In*: manual de producción de tomate en invernadero. Castellanos, J. Z. Ed. 1st. Intagri. México. 1-18 pp.

Cheiri, K.; Gelder, A. and Peet, M. M. 2018. Greenhouse tomato production. *In*: tomatoes. Heuvelink, E. Ed. 2nd. CABI. 276-313 pp. Doi: 10.1079/9781780641935.0276.

Contreras, M. E.; Arroyo, P. H.; Ayala, A. J.; Sánchez, D. C. F. y Moreno, P. E. C. 2013. Caracterización morfológica de la diferenciación floral en tomate (*Solanum lycopersicum* L.). Rev. Chapingo Ser. Hortic. 19(4):59-70. Doi: 10.5154/r.rchsh.2012.02.010.

FIRA. 2017. Fideicomisos Instituidos en Relación con la Agricultura. Panorama agroalimentario. Tomate rojo. https://www.fira.gob.mx/InfEspDtoXML/abrirArchivo.jsp?abreArc=65310.

Hartmann, H. T.; Kester, D. E.; Davies, F. T. and Geneve, R. L. 2014. Principles of propagation by cuttings *In*: plant propagation principles and practices. Harman, H.T and Kester, D. Ed. 8th. Pearson. 295-360 pp.

Hernández, R. and Kubota, C. 2016. Physiological responses of cucumber seedlings under different blue and red photon flux ratios using LEDs. Environ. Exp. Bot. 121:66-74. Doi: 10.1016/j.envexpbot.2015.04.001.

Heuvelink, E.; Li, T. and Dorais, M. 2018. Crop growth and yield. *In*: tomatoes. Heuvelink, E. Ed. 2nd. Cabi. 89-136 pp. Doi: 10.1079/9781780641935.0089.

Juárez, L. G.; Sánchez, D. C. F. y Contreras, M. E. 2000. Efectos del manejo de esquejes sobre el rendimiento de jitomate (*Lycopersicon esculentum* Mill.) en hidroponía. Rev. Chapingo Ser. Hortic. 6(1):19-23. Doi: 10.5154/r.rchsh.1999.03.026.

Moreno, P. E. C.; Sánchez, D. C. F.; Ruíz, D. M. and Contreras, M. E. 2021. Effect of population densities and paclobutrazol applications on seedling quality and yield in tomato. Rev. Chapingo Ser. Hortic. 27(1):5-17. Doi: 10.5154/r.rchsh.2020.05.010.

Moreno, P. E. C.; Sánchez, D. C. F.; Ruiz, D. M.; González, M. L.; Contreras, M. E. y Messina, F. R. U. 2016. Métodos de enraizamiento de esquejes para la producción de jitomate (*Solanum lycopersicum* L.) hidropónico. Rev. Agroproductividad. 9(10):50-55.

Sánchez, D. C. F. y Moreno, P. E. C. 2017. Diseño agronómico y manejo de invernaderos. Universidad Autónoma Chapingo. Chapingo, Texcoco, Estado de México. 59-78 pp.

Sánchez, D. C. F.; Bastida, C. O. A.; Moreno, P. E. C.; Contreras, M. E. y Sahagún, C. J. 2014. Rendimiento de jitomate con diferentes métodos de cultivo hidropónico basados en doseles escaleriformes. Rev. Chapingo Ser. Hortic. 20(3):239-251. Doi: 10.5154/r.rchsh.2013.10.037.

Sánchez, D. C. F.; Moreno, P. E. C. and Contreras, M. E. 2012a. Development of alternative commercial production of vegetables in hydroponics systems I: tomato. Acta Hortic. 947:179-187. Doi: 10.17660/ActaHortic.2012.947.22.

Sánchez, D. C. F.; Moreno, P. E. C. y Contreras, M. E. 2006. Reducción del ciclo de crecimiento en pepino europeo, mediante trasplante tardío. Rev. Fitotec. Mex. 29(2):87-90.

Sánchez, D. C. F.; Moreno, P. E. C.; Coatzín, R. R.; Colinas- León, M. T. y Peña-Lomelí, A. 2010. Evaluación agronómica y fisiotécnica de cuatro sistemas de producción en dos híbridos de jitomate. Rev. Chapingo Ser. Hortic. 16(3):207-214.

Sánchez, D. C. F.; Moreno, P. E. C.; Morales, M. A.; Peña, L. A. y Colinas L. M. T. 2012b. Densidad de población y volumen de sustrato en plántulas de jitomate (*Lycopersicum licopersicon* Mill.). Agrociencia. 46(3):255-266.

Sánchez, D. C. F.; Moreno, P. E. C.; Pastor, Z. O. A. y Contreras, M. E. 2017. Disposición de plantas de tomate en doseles en forma de escalera bajo dos densidades de población. Rev. Fitotec. Mex. 40(3):333-340. Doi: 10.35196/rfm.2017.3.333-340.

Sánchez, D. C. F.; Portillo, M. L.; Moreno, P. E. C.; Magdaleno, V. J. J. y Vázquez, R. J. C. 2021. Efectos del volumen de contenedor y densidad de plántula sobre trasplante tardío y número de flores en jitomate. Rev. Chapingo Ser. Hortic. 27(2):71-84. Doi: 10.5154/r.rchsh.2020.06.015.

SAS. Institute. 2002. Statistical Analysis System. SAS/STAT 9.1 user's guide. Cary, NC. USA.

SIAP. 2021. Servicio de Información Agroalimentaria y Pesquera. Anuario estadístico de la producción agrícola. SAGARPA. Ciudad de México, México. http://infosiap.siap.gob.mx:8080/agricola_siap_gobmx/ResumenProducto.do.

Sosa, B. A. y Ruíz, I. G. 2017. La disponibilidad de alimentos en México: un análisis de la producción agrícola de 35 años y su proyección para 2050. Papeles de Población. 23(93):207-230. Doi: 10.22185/24487147.2017.93.027.

Tadeo, R. F. y Gómez, C. A. 2013. Fisiología de las plantas y el estrés. *In*: fundamentos de fisiología vegetal. Azcón-Bieto, J. y Talón, M. Ed. 2nd. McGraw-Hill Interamericana. 577-598 pp.

Taiz, L.; Zeiger, E.; Møller, I. M. and Murphy, A. 2015. Plant physiology and development. 6th. Sinauer associates, sunderland, Inc. Publisher. Suderland, Massachusetts, USA. 171-200 pp.

Wien, H. C. 1999. Transplanting. *In*: Wien, H. C. Ed. The physiology of vegetable crops. CABI Publishing. Cambridge, UK. 37-67 pp.