Article

Growth, yield and quality of poblano chili pepper grown in hydroponics under greenhouse

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Abstract

The poblano chili pepper crop sown in soil in the Alto Atoyac in Puebla has been affected by the presence of diseases caused by fungi, bacteria and nematodes, generating losses in yield and reduction of the sowing area. The production under greenhouse and hydroponics is an alternative solution to this problem, since it allows the development of crops in a controlled environment using inert substrates, ensuring a greater percentage of production. The objective was to evaluate the growth, yield and fruit quality of two local varieties of poblano chili pepper (Tlacotepec and Tlalancaleca) and a commercial variety (San Luis), supplied nutritionally by three concentrations of the Steiner nutrient solution under greenhouse and hydroponics in order to know their agronomic and productive behavior. A 3x3 factorial treatment design in a completely randomized experimental design was considered. The variables evaluated were: plant height, stem thickness, number of leaves, number of bifurcations, number of flowers, yield and fruit quality. The results showed that the San Luis variety reached the highest yield and fruit quality. As for the three concentrations of nutrient solution, there was no significant effect on the yield and the agronomic behavior of creole varieties in the substrate, greenhouse and hydroponics system may be an option for the production of poblano chili pepper in the Alto Atoyac region.

Keywords: *Capsicum annuum* L., nutrient solution, protected agriculture.

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Introduction

Chili (*Capsicum annuum* L.) is native to Mexico and one of the most important crops worldwide, it is a symbol that gives identity to Mexicans in various cultures and has great impact on national and international gastronomy (Aguirre and Muñoz, 2015), its fruits are consumed fresh and dry to provide color, flavor and aroma to countless dishes. Mexico is a producer of various varieties of the genus *Capsicum*, where around 158 000 ha of green chili are grown with an average production of 3.3 million tonnes per year, making it the second largest producer worldwide after China (SIAP, 2019).

In Puebla, a great diversity of chili peppers is produced, among them, the creole poblano chili pepper for having a great economic, sociocultural and gastronomic importance (Rodríguez *et al*., 2007), this is produced mainly in the Alto Atoyac region in the traditional open-field system, the municipalities that stand out in the production of poblano chili pepper are: San Martín Texmelucan, San Lorenzo Chiautzingo, San Salvador el Verde, San Felipe Teotlalcingo, San Matías Tlalancaleca, among others (SIAP, 2019).

However, in recent years the crop has been affected by various factors and phytosanitary problems, predominating diseases in the soil caused by fungi, bacteria and nematodes, responsible for the reduction of yield and planting area, which has generated economic losses for producers who do not have adequate technological packages to face these problems (González-Pérez *et al*., 2004; Rodríguez *et al*., 2007; Pérez *et al*., 2017).

Given this problem, it is essential to look for alternative systems to produce poblano chili pepper, one of them is hydroponics that is characterized by not requiring soil as a biotic and support system for plants and offers the possibility of obtaining high yields (Velasco *et al*., 2011; Sánchez-del-Castillo *et al*., 2014). In the hydroponic system, the nutrients that plants require are supplied through a nutrient solution, one of the most used solutions for the production of *Capsicum annuum* is the nutrient solution formulated by Steiner (Beltrán-Morales *et al*., 2016; Luna-Fletes *et al*., 2018, San Juan *et al*., 2019), this solution must have the appropriate concentration of nutrients because the yield and quality of the fruits will depend on it (San Juan *et al*., 2019).

To successfully conduct the cultivation of poblano chili pepper in this system, it is necessary to carry out studies focused on agronomic management and nutrition, because of all the factors that influence the growth of the crop, plant nutrition is one of the most decisive (Alcántar-González *et al*., 2016). There is insufficient information related to nutrient management in poblano chili pepper grown under greenhouse and hydroponics, especially on creole or local varieties, nor is there a specific nutrient solution for the crop because research has focused primarily on cultivation in soil and open field.

Hence, the research question is related to identifying the agronomic behavior of creole varieties of poblano chili pepper in substrate, when they are subjected to the production system in greenhouse and hydroponics. Based on the above, the objective was to evaluate the growth, yield and fruit quality of two native varieties of poblano chili pepper (Tlacotepec and Tlalancaleca) and a commercial variety (San Luis), supplied nutritionally through three concentrations of the Steiner nutrient solution, in order to know their agronomic and productive behavior.

Materials and methods

The research was carried out in the protected agriculture unit of the College of Postgraduates located in San Agustín Calvario, San Pedro Cholula, Puebla, at 19° 03’ 18” north latitude and 98° 20’ 59” west longitude, with an altitude of 2 166 m (INEGI, 2010), during the 2017 spring-autumn period. Two local varieties of poblano chili pepper from the Alto Atoyac region, Puebla, identified as Tlacotepec and Tlalancaleca, from the municipalities of Tlacotepec de José Manzo (19º 27’ 94” north latitude and 98º 49’ 12” west longitude) and San Matías Tlalancaleca (19º 17’ 30” north latitude and 98º 27’ 42” west longitude) were evaluated, the San Luis variety of the Caloro company was also evaluated, these materials are cultivated by the producers of the region in the traditional field system.

The sowing was carried out in polystyrene trays of 200 cavities, peat (peat moss) brand Sunshine mixture 3 was used as substrate, the emergence occurred 16 days after sowing. The transplantation was performed 32 days after the emergence in black polyethylene bags (40 x 40 cm) with a capacity of 11 kg, which were filled with volcanic sand (red tezontle) with particles of size equal to or less than 2 mm in diameter, and in each bag two seedlings were placed deep in the root ball. During the 14 days after the transplantation (ddt), a daily irrigation was applied with a 75% diluted nutrient solution, from day 15 (ddt) the application of the treatments began.

The experimental design was a 3x3 factorial arrangement, the study factors were varieties: Tlacotepec (TC), Tlalancaleca (TL) and Ancho San Luis (SL) and concentration of the nutrient solution (SN) Steiner: 50, 75 and 100%. Treatments were distributed under a completely randomized design with 12 repetitions. The experimental unit was a bag with substrate with two plants. The planting density was 4.2 plants m^{-2}.

The nutrient solution used was the Universal one proposed by Steiner (1984), with 12, 1 and 7 me L^{-1} of NO_3^-, $H_2PO_4^-$ and SO_4^{2-} for anions and 7, 9 and 4 me L^{-1} of K^+, Ca^{2+} and Mg^{2+} for cations, in addition to: 2, 0.7, 0.02, 0.09, 0.05 and 0.04 mg L^{-1} of Fe, Mn, Cu, Zn, B and Mo for a solution of 100% concentration. The solution was prepared with soluble commercial fertilizers and applied using an open system. For the 100% concentration the following sources of fertilizers were used: KNO_3, $Ca(NO_3)_24H_2O$, KH_2PO_4, $MgSO_47H_2O$, K_2SO_4 and the Ultrasol Micro-Mix micronutrient commercial complex of SQM, the solutions at 75 and 50% were prepared proportionally. The irrigations were applied once a day manually and varied depending on the growth of the plants, on average, 250 ml pot^{-1} in the establishment stage and 1 L pot^{-1} in the stage of development, flowering and fruiting were applied. To avoid the accumulation of salts in the substrate, an irrigation with well water was applied every seven days.

The characters evaluated in the plant were: height, it was measured with a tape measure from the base of the stem to the last leaf apex, stem thickness, it was measured with a digital vernier at 2 cm from the level of the substrate, number of bifurcations, number of leaves and number of flowers, they were determined by counting them directly from the main stem, yield, the number of fruits and the total weight (kg) were recorded at the time of harvest, fruit characterization, it was determined with the Mexican Standard: NMX-FF-025-SCFI-2014 and fruit length was recorded with a graduated rule, fruit width with a digital vernier and fruit weight with an electronic scale. The growth variables were recorded weekly from the first day of transplantation until to 154 ddt, the yield and fruit quality were recorded at 97, 113, 127, 148 and 159 ddt.

The data obtained were subjected to an analysis of variance and a Tukey's mean comparison test ($p < 0.05$) with the Statistical Analysis System program version 9.0 (SAS Institute, 2002). Additionally, the nonlinear NLIN model proposed by Hunt (2017) was applied to the growth variables, in order to observe the adjustment of each parameter evaluated in the greenhouse, when applying a mathematical model.

Results and discussion

Growth

The analysis of variance showed for the variety factor (VAR) highly significant differences in plant height (AP), stem thickness (GT) and number of leaves (NH), significant differences in number of bifurcations (NB) and non-significant differences in the number of flowers (NF). No significant differences were found with respect to the effect of the concentration of the nutrient solution (SN), only in NH the differences were highly significant (Table 1).

Table 1. Mean squares and statistical significance of the growth variables, in poblano chili pepper grown in hydroponics and greenhouse.

FV	GL	AP	Fc	GT	Fc	NB	Fc	NH	Fc	NF	Fc
		154 ddt						91 ddt		42 ddt	
SN	2	242.8	0.9 ns	0.7	2 ns	55.7	1.3 ns	387	5.6**	7.6	2.8 ns
VAR	2	9955.4	37.6**	163.4	480.3**	297.6	6.8*	4241.2	61.1**	22.3	8.3**
SN∗VAR	4	2217.6	8.4**	0.9	2.6*	53.7	1.2 ns	83.9	1.2 ^{ns}	6.7	2.5*
Error	99	264.5	-	0.3	-	43.6	-	69.4	-	2.7	-
CV	-	9.9	-	4.7	-	15	-	7	-	20.4	-

FV= source of variation; GL= degrees of freedom; Fc= F calculated; SN= nutrient solution; VAR= variety; AP= plant height; GT= stem thickness; NH= number of leaves; NB= number of bifurcations; NF= number of flowers; CV= coefficient of variation (%); *, **= statistical significance at 0.05 and 0.01 probability; ns= not significant.

According to the results of the mean comparison test (Table 2), in the AP variable no significant differences were found due to the application of the nutrient solution, only significant differences were found between varieties. This indicates that the application of a high concentration of nutrient solution does not necessarily guarantee a higher AP, because as mentioned by Magdaleno-Villar *et al*. (2006); San Martín-Hernández *et al*. (2012), generally, when increasing the concentration of nutrients, the electrical conductivity (CE) tends to rise and reduces the absorption capacity of water and nutrients, which causes the growth of the plant to be limited.

Table 2. Comparison of means of growth variables in three varieties of poblano chili pepper, cultivated with three concentrations of nutrient solution.

Concentration of SN (%)	AP (cm)	GT (mm)	NB por plant	NH por plant	NF por plant
	154 ddt			91 ddt	42 ddt
50	160.7 a	12.3 a	43.1 a	115.7 b	7.6 a
75	165.6 a	12.5 a	45.5 a	118.2 ab	8 a
100	164.5 a	12.3 a	43.6 a	122.2 a	8.5 a
DHS	9.1	0.3	3.7	4.7	0.9
Variety					
San Luis	147.8 c	14.8 a	41.2 b	106.2 b	8.6 a
Tlacotepec	162.2 b	11.1 b	44.1 ab	125.3 a	8.4 a
Tlalancaleca	180.9 a	11.2 b	47.0 a	124.7 a	7.1 a
DHS	9.1	0.3	3.7	4.7	0.9

Means with the same letter in the same column are statistically equal (Tukey, $p \leq 0.05$); DHS= honest significant difference. AP= plant height; GT= stem thickness; NH= number of leaves; NB= number of bifurcations; NF= number of flowers; SN= nutrient solution.

On the other hand, Figure 1 shows the growth curves adjusted for PA, where it can be observed that the highest values were obtained in the treatment TL75% (173.9 cm), followed by the treatment TC75% (151.4 cm) and SL50% (138.8 cm). Toledo-Aguilar *et al*. (2011) reported plant height values in 49 native varieties of poblano chili pepper grown in open field, which ranged from 38 to 57 cm, the varieties evaluated in this study showed a height three times greater due to the conditions in which they were cultivated, which coincides with what was found by Beltrán-Morales *et al*. (2016), who obtained high values in plant height in jalapeño chili pepper produced under greenhouse in contrast to those grown in field.

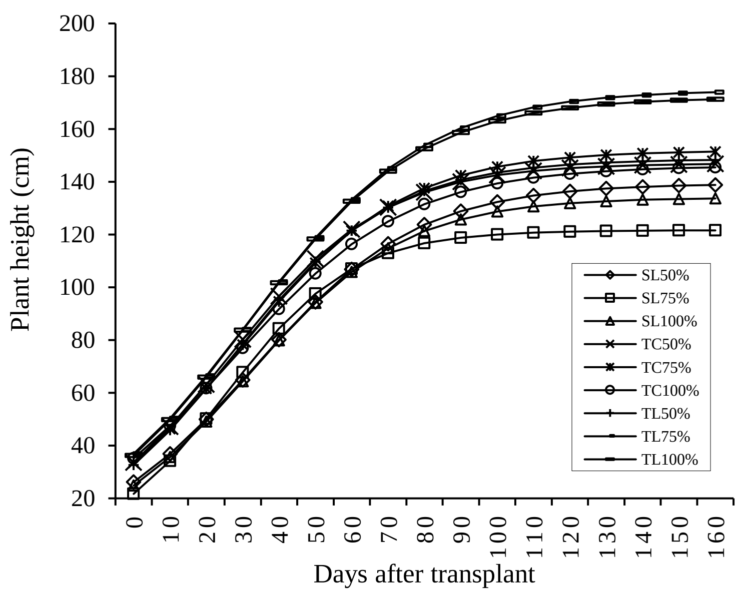

Figure 1. Growth dynamics of plant height in three varieties of poblano chili pepper, grown with three concentrations of the Steiner nutrient solution.

Usually, in controlled greenhouse conditions, if the plant is subjected to a low light intensity, the internodes of the stems lengthen resulting in a higher plant height, for this reason one of the factors that should also be considered in the production of *Capsicum* is solar radiation because it directly influences the growth of the crop (Hernández-Verdugo *et al*., 2015; Alemán *et al*., 2018).

In stem thickness, the analysis of variance showed significant differences for the VAR x SN interaction (Table 1), GT was favored in the San Luis variety (15 mm) compared to the local varieties, where an average stem thickness of 11 mm was obtained (Table 2). The data obtained are similar to those reported by Elizondo-Cabalceta and Monge-Pérez (2017), who obtained values for stem thickness between 12.5 and 15.8 mm in 12 genotypes of sweet pepper grown under greenhouse conditions; on the other hand, Moreno *et al*. (2011) reported stem thicknesses ranging from 14 to 16 mm in 12 commercial varieties of bell pepper grown under greenhouse and hydroponics.

In Figure 2, it can clearly be observed that the outstanding treatments were SL100%, SL50% and SL75%, in contrast to the local varieties which presented lower values, such is the case of TC50%, however, they coincide with the range of values obtained for stem thickness from 8.3 to 12.6 mm in chili pepper plants grown under protected conditions (Moreno *et al*., 2014).

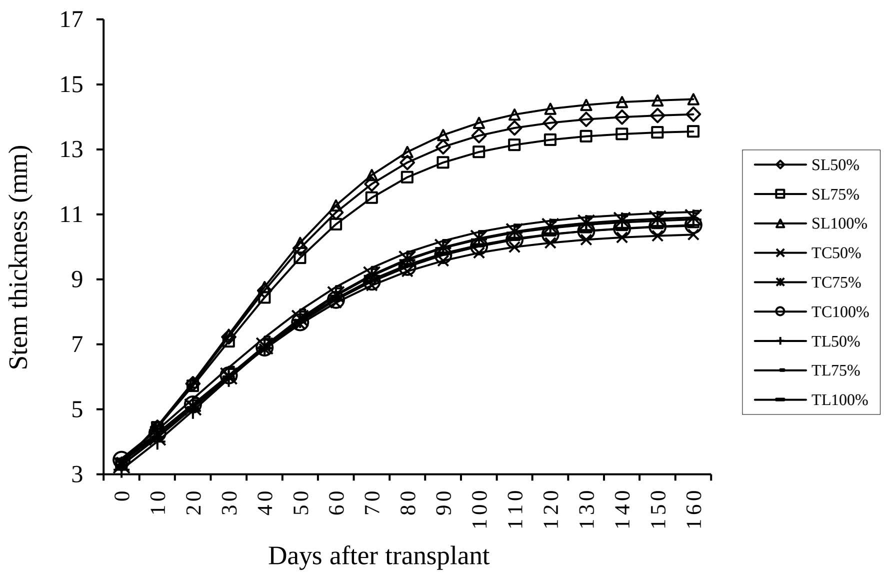

Figure 2. Growth dynamics of stem thickness in three varieties of poblano chili pepper, grown with three concentrations of the Steiner nutrient solution.

In NH, the results at 91 ddt are reported, because the maximum values for this variable were recorded during this sampling. The VAR and SN factors significantly affected this variable (Tables 1 and 2), it was found that the response of the poblano chili pepper varieties to the concentration of the nutrient solution was linear, as the concentration of the nutrient solution increased, the NH also increased. As indicated in Figure 3, the treatments that accumulated a higher NH were TC100%, TC75%, TL100% and TL75%, the lowest number of leaves corresponds to the treatment SL75%.

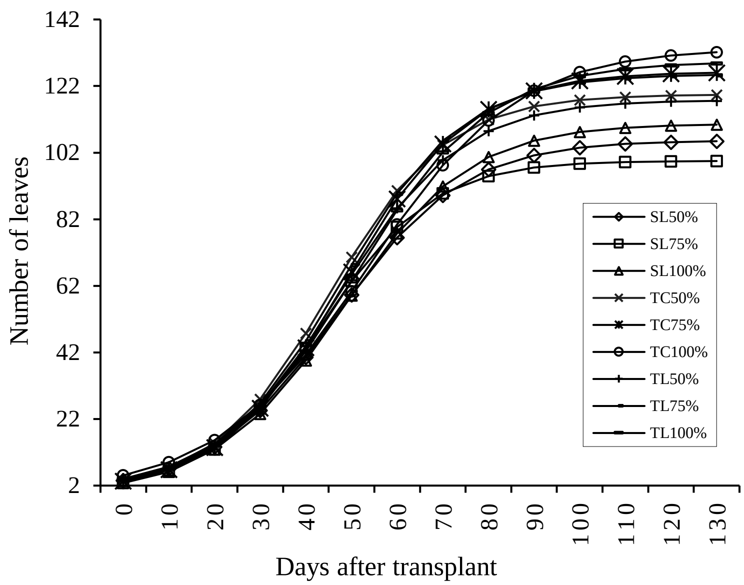

Figure 3. Growth dynamics of the number of leaves in three varieties of poblano chili pepper, cultivated with three concentrations of the Steiner nutrient solution.

These results are similar to those published by Fawzy *et al*. (2012) in *C. annuum cv* 'California Wonder', who observed a higher vegetative growth in plants with the application of a 100% concentrated nutrient solution of chemical fertilizer. In addition, the index of leaf area in poblano chili pepper plants grown under greenhouse conditions indicates that a greater amount of foliage significantly influences the capture of light and CO_2, because absorbing a greater amount of photosynthetically active radiation, the foliar production and the synthesis of compounds essential for the development of the plant increase (Berrospe-Ochoa *et al*., 2015; Mendoza-Pérez *et al*., 2017).

The variable number of bifurcations (NB) was different in the three varieties (Table 1), but there was no effect by the nutrient solution. In the Tlalancaleca variety, a higher value was obtained for this variable (47 bifurcations), compared to the Tlacotepec variety (44 bifurcations) and the San Luis variety (41 bifurcations). This response can be seen in Figure 4, where the treatments TL75%, TL100% and TC75% stand out, in contrast to the treatments SL50% and SL75%, as happened in AP, since NB is directly related to AP, because the higher the plant height, the highest the number of bifurcations, and, consequently, it could be expected that the number of fruits per plant will also increase since in each bifurcation, the plants can develop a flower that can become a potential fruit (Ponce *et al*., 2012).

For NF, the results at 42 ddt are presented because at this stage the poblano chili pepper plants reached their maximum expression in this variable. NF showed statistically significant differences between the varieties evaluated, but not by the application of the Steiner nutrient solution (Table 1).

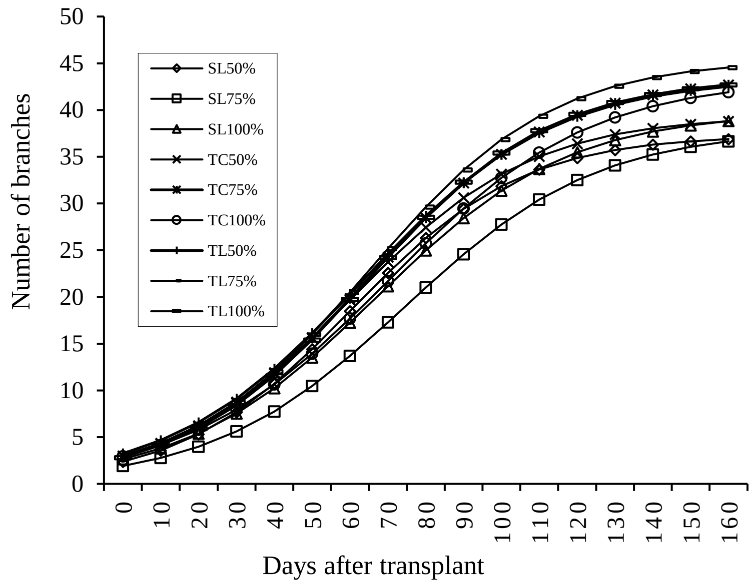

Figure 4. Growth dynamics of the number of bifurcations in three varieties of poblano chili pepper, cultivated with three concentrations of the Steiner nutrient solution.

In Figure 5, it can be observed that throughout the crop cycle in the different samplings carried out, there was an increase and a decrease in the number of flowers, this because the plants had flower abortion and many of the flowers counted did not become fruit, therefore, the growth in this variable was not linear. Reséndiz-Melgar *et al*. (2010) mention that chili pepper plants have sympodial growth, and generally solitary flowers are produced in each bifurcation.

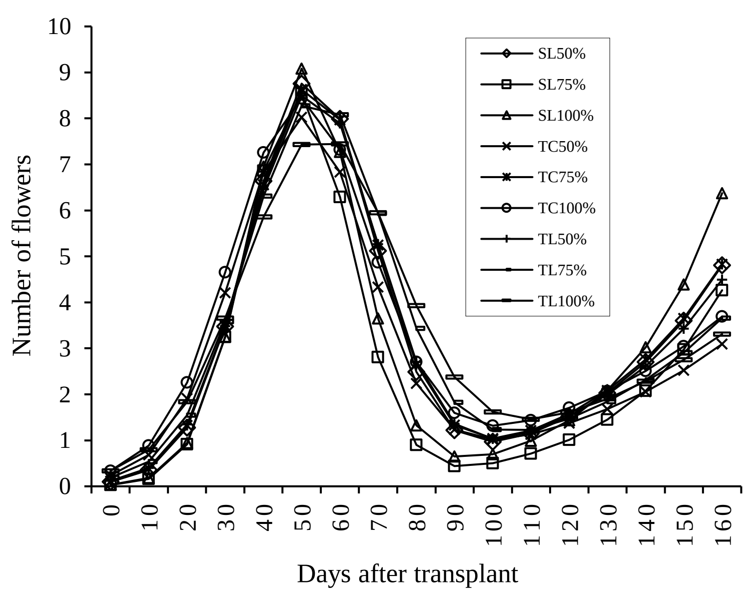

Figure 5. Growth curves of number of flowers, in three varieties of poblano chili pepper grown with three concentrations of nutrient solution.

If the plants are allowed to grow freely, the first six to 12 flowers will set fruit, but the high demand for assimilates for their rapid growth causes abortion of a high percentage of the flowers generated subsequently. The main causal agents of flower drop are associated with high temperatures, low radiation intensity, presence of fruit in the rapid growth stage and various biotic agents (Moreno *et al*., 2011; López-Gómez *et al*., 2017).

Yield

In this variable there were no statistically significant differences due to the application of the treatments (Table 3), the different concentrations of SN had no effect on yield. On the other hand, in the evaluated varieties there were significant differences as can be seen in Tables 3 and 4, where the yield was statistically higher in the commercial variety San Luis (1.42 kg plant^{-1}) followed by the varieties Tlalancaleca (1.05 kg plant^{-1}) and Tlacotepec (0.99 kg plant^{-1}).

The average yield reported for the poblano chili pepper crop produced in field varies from 1.4 t ha^{-1} to 3.2 t ha^{-1} (Velásquez-Valle *et al*., 2014; Pérez *et al*., 2017) and according to the results obtained in this research, yields of up to 4 kg m^{-2} can be obtained with native varieties of the region and 6 kg m^{-2} with commercial varieties, data similar to those reported by Mendoza-Pérez *et al*. (2017) in the poblano chili pepper crop variety Capulín, Ramos-Gourcy and De Luna-Jiménez (2006) in three varieties of ancho chili pepper and Aguilar *et al*. (2005) in San Luis ancho chili pepper.

Table 3. Analysis of variance of yield and number of fruits, in poblano chili pepper grown in hydroponics and greenhouse.

FV	GL	Yield (kg plant^{-1})			No. of fruits (plant^{-1})		
		CM	Fc	Significance	CM	Fc	Significance
Nutrient solution (SN)	2	0.06	1.72	0.1855	61.2	2.26	0.1103
Variety (VAR)	2	1.95	53.65	<0.0001	393.7	14.55	<0.0001
SN*VAR	4	0.05	1.24	0.2998	95.5	3.53	0.0102
Error	88	0.04	-	-	27.1	-	-
CV	-	16.59	-	-	22.2	-	-

FV= source of variation; GL= degrees of freedom; CM= mean squares; Fc= F calculated; SN= nutrient solution; VAR= variety; CV= coefficient of variation (%); Sig= statistical significance at 0.05 and 0.01 probability.

For the variable number of fruits, significant and highly significant differences were found ($p \leq 0.05$) between the three evaluated varieties of poblano chili pepper (Table 3), the highest number of fruits was obtained with the varieties Tlacotepec and Tlalancaleca (Table 4). The applied concentrations (50, 75 and 100%) of SN did not affect the variable number of fruits. According to Martínez *et al*. (2018), the effect caused by Ca $(NO_3)_2$ in low concentrations consists in generating a higher production of fruits per plant since as this fertilizer increases, decreasing yields can be caused.

Table 4. Comparison of means of yield and number of fruits in three varieties of poblano chili pepper.

Concentration of SN (%)	Yield (kg $plant^{-1}$)	Number of fruits by plant
50	1.2 a	24 a
75	1.2 a	24.3 a
100	1.1 a	21.9 a
DHS	0.1	2.9
Variety		
San Luis	1.4 a	19.8 b
Tlacotepec	1 b	24.2 a
Tlalancaleca	1 b	26.3 a
DHS	0.1	2.9

Means with the same letter in the same column are statistically equal (Tukey, $p \leq 0.05$); DHS= honest significant difference; SN= nutrient solution.

Fruit quality

The characteristics of fruit quality of poblano chili pepper were not affected by the concentration of the nutrient solution, according to the results of the mean comparison test, significant differences were present only in the San Luis variety (Table 5). In the creole varieties, 100% of the fruits had a weight between 80 and 110 g with the application of any concentration of SN, while in the San Luis variety, the highest number of fruits that were grouped between 80 and 110 g was obtained by applying SN at 75%. Wamser *et al*. (2017) indicate that high concentrations of nitrogen in the nutrient solution increase the quantity of fruits per plant because it is the main component that influences the increase of fruit yield; nevertheless, at high concentrations in the nutrient solution, it tends to decrease the fruit weight because of the increase in the electrical conductivity in the substrate solution.

Table 5. Characterization of fruit size of three varieties of poblano chili pepper grown with three concentrations of nutrient solution.

Weight (g)	Concentration of the nutrient solution (%)			DHS
	50	75	100	
		San Luis		
Small (80-110)	9.42 ab	10.8 a	7 b	3.2
Medium (110-129.9)	1.2 a	0.5 a	1.1 a	1
Large (130-150)	0.2 a	0.3 a	0.4 a	0.5
Extra large (> 150)	0.1 a	0.1 a	0 a	0.2
		Tlacotepec		
Small (80-110)	13.3 a	10.3 a	11.1 a	2.9
		Tlalancaleca		
Small (80-110)	10.7 a	13.4 a	12.6 a	3.2

Means with the same letter on the same row are statistically equal (Tukey, $p \leq 0.05$); DHS= honest significant difference.

On the other hand, Ramírez-Luna *et al*. (2005) presented similar results, who, in habanero chili pepper plants produced under greenhouse, obtained fruits of smaller size compared to those produced in field, because the plants received a lower intensity of light, this condition favored the development of plants with greater height, thin stems, but fruits of small size.

Regarding fruit length, there were significant effects due to the application of SN in the SL and TC varieties (Table 6), where the 100% concentrated nutrient solution promoted the longest fruits (12-14 cm) in both varieties. San Juan *et al*. (2019) reported that, in huacle chili pepper, they obtained a greater response in the variables length and width of fruit with the application of the Steiner nutrient solution with a higher concentration of nutrients.

Table 6. Mean squares and statistical significance for the variables length and width of fruit, in three varieties of poblano chili pepper grown with three concentrations of nutrient solution.

FV	GL	Length (cm)				Width (cm)			
		CH < 10	MD 10-11.9	GD 12-140	EG >14.0	CH <6	MD 6-6.9	GD 7- 8	EG >8
San Luis									
% of SN	2	11.1 ns	31.4**	3.6 ns	4.7*	48.8**	1.7 ns	5.1 ns	0.2 ns
Error	33	3.5	3.4	2.7	1.4	7.1	2.5	1.8	0.3
CV		102.6	57	43	81.6	63.5	45.6	57.7	142.7
Tlacotepec									
% of SN	2	6 ns	10 ns	8.1 ns	8.5*	41.7*	2.1 ns	0.03 ns	-
Error	33	2.2	5.2	7	1.9	9.5	0.9	0.03	-
CV		67.1	53	65.7	135.4	28.2	159.5	600	-
Tlalancaleca									
% of SN	2	2.1 ns	0.4 ns	2.2 ns	5.4 ns	39 ns	1 ns	1 ns	-
Error	33	2.9	6.9	5.3	2.6	15.1	2.3	0.6	-
CV		64.7	57.7	61.8	124.3	37.6	100.5	202.7	-

FV= source of variation; GL= degrees of freedom; E= error; CV= coefficient of variation; CH= small; MD= medium; GD= large; EG= extra-large (%); SN= nutrient solution; *= statistical significance at 0.05; ns= not significant.

In fruit width there was also no effect of SN, in the SL variety, SN at 100% caused the highest percentage of fruits with a thickness between 7 and 8 cm, in the TL variety more than 90% of the fruits presented a width less than 6 cm with any nutrient solution, while in the TC variety, SN at 50% led to the highest number of medium-sized fruits. Santiago *et al*. (2018) reported that the fruits of ancho poblano chili pepper grown in open field reached a length of 13.95 cm and a diameter of 6.25 cm, values that, although not obtained under the same conditions, are similar to those obtained in this work in the San Luis variety.

Conclusions

Of the varieties studied, San Luis reached the highest yield and fruit quality, but it was the local varieties that presented the highest number of fruits, although with lower quality. With respect to the concentrations of the nutrient solutions studied, there were no statistically significant differences in the most important variables such as yield and number of fruits. The agronomic behavior of the creole varieties evaluated in the substrate, greenhouse and hydroponics system is comparable with the San Luis variety and it may be an option for the production of poblano chili pepper in the Alto Atoyac region.

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