Article

Effect of number of stems in the production and quality of tomato grown in greenhouse

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Abstract

The tomato is one of the most consumed vegetables in the world, its production, quality and size is affected by climatic conditions, water needs and management of number of stems. The objective of this work was to evaluate the tomato production and some quality variables, in three management conditions, depending on the number of stems. The work was carried out in a greenhouse of the Postgraduate School. It was transplanted on April 20, 2015 with tezontle as a substrate, under drip irrigation. The experiment consisted of three treatments (T1), with one (T1), two (T2) and three (T3) stems per plant. Samples were taken in the 1st, 5th and 10th clusters of the plant, to determine the yield, size, firmness, total soluble solids, titratable acidity, pH and amount of vitamin C. Yields of 6.55, 5.91 and 5.45 kg pl^{-1} were obtained for T1, T2 and T3. T1 was better with 69, 23, 8 and 1% of large, medium, small and very small size per plant. In the quality variables, total soluble solids and pH increased as the number of stems per plant increased compared to the firmness that decreased. Higher vitamin C content was found in the 10th cluster of T3. It was observed that increasing the number of stems increased the amount of fruit per plant, but the size and firmness decreased, therefore it is recommended to use T1 for export fruits and T2 for internal consumption.

Keywords: *Solanum lycopersicum* L., firmness, pH, titratable acidity, total soluble solids, vitamin C.

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Introduction

The tomato or red tomato (*Solanum lycopersicum* L.) is one of the most consumed vegetables in the world (Chapagain and Wiesman, 2004) and the main vegetable grown under greenhouse. The system of intensive tomato production under greenhouse, which is normally practiced in Europe and the United States of America, uses varieties of undetermined habit and low population densities that vary from two to three plants per square meter, where the stems of the plants frequently they are pruned and a single stem that reaches more than seven meters in length is left to harvest 15 or more clusters per plant, in a single crop cycle per year (Chapagain and Wiesman, 2004). This production system in Mexico is relatively new and has generated an impact on the increase in cultivated area, productivity, profitability and quality in recent years.

Tomato is a healthy basic product due to its low content in kilocalories and fat and its content in fiber, proteins, vitamins A, C, E and potassium. It is used throughout the world in different presentations, either raw as part of salads, as an ingredient in sauces, broths and stews or processed, in the form of sauces, purées, juices or pasta (Vitale and Pomilio, 2010).

Tomatoes are climacteric fruits and their maturation is accompanied by changes in taste, texture, color and aroma. During this process chlorophyll is degraded and carotenoids are synthesized, such as lycopene (antioxidant that gives the color red) and β-carotene (precursor of vitamin A), gibberellins, quinones and sterols (Fraser *et al*., 1994). Marin-Rodríguez *et al*. (2002) notes that the fruit loses firmness, due to physical and chemical changes associated with the degradation of the cell wall and the solubilization of pectins, by the enzymes pectinesterase (PE), polygalacturonase (PG) and pectatoliase (PL).

When the fruit is destined to agro-industry, its main quality variables are dry weight, total soluble solids, titratable acidity (equivalent of citric acid), pH, viscosity (bostwick flow) and color. Since the values of the fruit pulp can be predicted, from the same measurements made in fresh homogenized fruit also called pulp or puree, the analyzes must be carried out on the fruits at the time of harvest (Renquist and Reid, 1998).

The quality of the fruit is evaluated by the appearance, color, texture, nutritional value, composition in ripeness of consumption, health, taste and aroma. Flavor is measured by soluble solids and organic acids. The quality of postharvest and the shelf life of the fruits is controlled by the state of maturity in the harvest (Alam *et al*., 2006). The flavor is the result of various volatile and non-volatile aromatic components and a complex interaction between them (Yilmaz, 2001).

Usually, the fruit is consumed with its maximum organoleptic quality, which occurs when the fruit has completely reached the red color, but before excessive softening. Therefore, color is the most important external characteristic in the determination of the point of maturation and post-harvest life, and a determining factor in the purchase decision by consumers. The red color is the result of the degradation of chlorophyll, as well as the synthesis of chromoplasts (Fraser *et al*., 1994).

There is limited information on tomato production under protected conditions. One of the variables of agronomic management associated with their productivity is the number of stems with a higher number of stems, the higher the yield; however, the response variables that determine its quality may be affected.

The objective of this work was to evaluate the production and some response variables that determine the quality and size of tomato fruits, grown in greenhouse, with three management conditions, depending on the number of stems, in three parts of the plant.

Materials and methods

The work was carried out in a greenhouse located in the Campus Montecillo, of the College of Postgraduates, state of Mexico, whose geographic coordinates are 19.96º north latitude and 98.9º west longitude, with an altitude of 2 244 m. The greenhouse used in this study is a type of central Mexico, with three naves with metal structures and high density polyethylene plastic covers, with 75% transmissivity, with anti-insect mesh on the side walls, ventilation is passive through side vents and manual opening zeniths.

In the zone an annual average temperature of 15.3 ºC and an annual pluvial precipitation of 603 mm is registered. The average annual evaporation is 1 743 mm. The average temperature in the hottest month is 18 ºC and in the coldest month of 11 ºC. The rainy season is from May to October, with an average maximum in July of 130 mm, and the dry season is from November to April. The climate is classified as temperate-cold.

Tomato seeds of Cid F1 variety of indeterminate growth were used. It was planted in germination trays on march 5, transplanted on April 20 and the harvest was completed on September 20, 2015. The plants were maintained at 1, 2 and 3 axes through pruning of lateral buds, and they sprouted on July 8, 2015, on the tenth floral cluster. The plantation frame was staggered, with a separation of 40 cm between plants and 40 cm between lines, transplanted in 35 × 35 cm black polyethylene bags with red tezontle as substrate, in beds with dimensions of 1.2 m wide by 20 m long and, with density of plantation of 3 plants m^{-2}.

The treatments (T) consisted of three management conditions, depending on the number of stems per plant: with one (T1), two (T2) and three (T3) stems per plant. The area of each treatment was 53 m^2 with a total area of 159 m^2. The distribution of the treatments was done in random blocks with 4 repetitions whose dimensions were 10 m^2.

The irrigation system was drip, with superficial irrigation line of 16 mm in diameter. Each irrigating line had self-compressed drippers separated at 40 cm and an expense of 4 L h^{-1} per dropper, with an operating pressure of 0.7 kg cm^{-2}.

Irrigation was applied daily and its number and duration was different according to the phenological stage of the crop at intervals of each hour. In the first 30 days after the transplant, 5 irrigations were applied, at 10:00, 12:00, 13:00, 14:00 and 15:00, with a duration of 3 minutes in each irrigation; in the stage of beginning of flowering they were increased to 8 irrigations applied to the 9:00, 10:00, 11:00, 12:00, 13:00, 14:00, 15:00 and 16:00 h, with duration 4 min. In the stage of maximum demand and start of fruition, 10 irrigations were applied at 9:00, 10:00, 11:00, 12:00, 13:00, 14:00, 15:00, 16:00, 17:00 and 6:00 pm, with a duration of 5 minutes per irrigation. Irrigations were applied with Steiner nutrient solution with (osmotic pressure = -0.087 MPa) throughout the crop cycle.

Response variables in tomato quality

To determine the response variables of fruit quality, samplings were carried out in three parts of the plant: the first, in the 1^{st} cluster; the second, in the 5^{th} cluster and the third, in the 10^{th} cluster. Four fruits were selected per treatment and firmness, total soluble solids content (ºBrix), titratable acidity, pH and vitamin C content were determined.

Firmness: it was measured in the equatorial zone of the fruits, using a digital texturometer (Universal Force Five), with a scale of 0.1 up to 0.32% strength and a conical strut of 0.8 mm registering the reading in Newton (N) of the applied force until the penetration of the prop.

Total soluble solids (ºBrix): were determined in the juice of the fruit by means of a digital refractometer, Atago brand with scale from 0 to 32% and were expressed in ºBrix.

The pH: the 10 g of pulp were crushed with 50 mL of deionized water, filtered to remove the remains of plant tissue and in an aliquot of 5 mL, the pH was determined with a potentiometer.

Titratable acidity: it was evaluated according to the methodology of AOAC (1990), for which 10 g of pulp were homogenized in 50 mL of deionized water. A 10 mL aliquot was taken, which was neutralized with 0.1 N (NaOH) and phenolphthalein with indicator. The results were reported as percentage of citric acid, using the equation.

$$\%\ \text{Ac. citric}=\frac{(\text{mL NaOH spent})\text{x}(\text{N NaOH})\text{x}(\text{Meq.acid})\text{x}(\text{VT})\text{x}(100)}{(\text{Weight shows})\text{x}(\text{Aliquot})}$$

Where: N= normality; VT= total volume (mL of deionized water plus fruit weight); Meq= Miliequivalents of the acid found in greater proportion (citric acid= 0.064).

Vitamin C (ascorbic acid): determined according to the methodology of AOAC (1990). 20 g of fresh tissue were homogenized in 30 mL of oxalic acid solution (0.5%), an aliquot of 5 mL was taken and titrated with tilma solution (0.01%) until a visible pink color remained for 1 min. The concentration was expressed in mg 100 g^{-1} using ascorbic acid as a standard.

Total soluble solids-titratable acidity ratio: an indicator was obtained, which is the quotient between total soluble solids (SST or ºBrix) and titratable acidity (AT). It was calculated with the following equation:

$$\frac{\text{SST}}{\text{AT}}=\frac{^\circ\text{Brix}}{\text{acidez titulable}}$$

Where: SST/AT= ratio total soluble solids / titratable acidity; ºBrix= Brix degree of tomato juice; titulable acidity= expressed in citric acid

Evaluation of yield and number of fruits per plant

After the transplant, seven plants of each treatment were selected, to evaluate yield and number of fruits per plant, up to the tenth cluster. Once the fruits were harvested, they were counted and weighed on a scale, to calculate the yield (kg pl^{-1}) and number of fruits per plant.

Classification of fruit size

In each cut fruits were classified by size, in this work, the fruit was elongated (saladette) in the following categories (large, medium, small and very small), according to the minimum and maximum equatorial diameter, as mentioned Mexican Standard NMX-FF-031-1997 (Table 1).

Table 1. Size classification of tomato fruit elongated type (saladette).

Size	Diameter (mm)	
	Minimum	Maximum
Small	38	52
Medium	52	60
Big	60	71
Extra big	71	Hereafter

Statistical analysis of comparison of means

To determine the significant difference of the variables evaluated for the design of blocks at random, a comparison analysis of means was performed, with the Tukey test with a level of significance of 95%, with the statistical package MINITAB.

Results and discussion

Total number of fruits

In the Table 2 presents the total number of fruits, which were obtained in the repetitions of each treatment, where on average 62, 78 and 84 fruits were obtained per plant for T1, T2 and T3, respectively. Significant statistical differences were found in the mean values of the total number of fruits in the three treatments. The results obtained from this research are similar to the results reported by Villegas *et al*. (2004) with 47.1 tomato fruits variety Gabriela with planting density of 3.8 pl m^{-2} grown under greenhouse conditions.

Table 2. Total number of fruits obtained per plant in the three treatments.

Treatments	R1	R2	R3	R4	R5	R6	R7	Average
T1 (one stem)	59 b	60 b	65 b	67 b	65 b	57 b	61 b	62 b
T2 (two stems)	71 a	73 a	77 a	79 a	89 a	69 a	87 a	78 a
T3 (three stems)	77 a	80 a	78 a	84 a	99 a	83 a	76 a	84a

Values with the same letter in each column, are equal to each other (Tukey, 0.05).

Villegas *et al*. (2004) mentions that as the density of plantation per square meter increases, the total number of fruits per plant increases, but the size decreases, with size being an important variable for the selection and classification of fruits for export purposes.

Classification of fruit size

The Figure 1 presents a classification of the size of fruits harvested by treatment. The treatment of a stem (T1) was the best in terms of size refers to 69, 23, 8 and 1% of fruits category (large, medium, small and very small) per plant, respectively. The results obtained in this work are similar to those reported by Rodríguez *et al*. (2008), in tomato under greenhouse, since they found that 60% corresponded to extra-large size, 20% to first, 10% to second and 10% to loss.

In the treatment of two stems (T2) were obtained 49, 33, 17 and 1% fruits of size (large, medium, small and very small) per plant, respectively. The results obtained in this work are similar to that reported by Quintana-Baquero *et al*. (2010), in tomato under greenhouse they reported that 9% of extra-large size, 52% of first, 27% of second, 11% of third and 2% of fourth. For the treatment of three stems (T3), 37, 39, 23 and 2% of fruits of size (large, medium, small and very small) were obtained per plant, respectively. No literature review of performance, size and quality of this treatment was found.

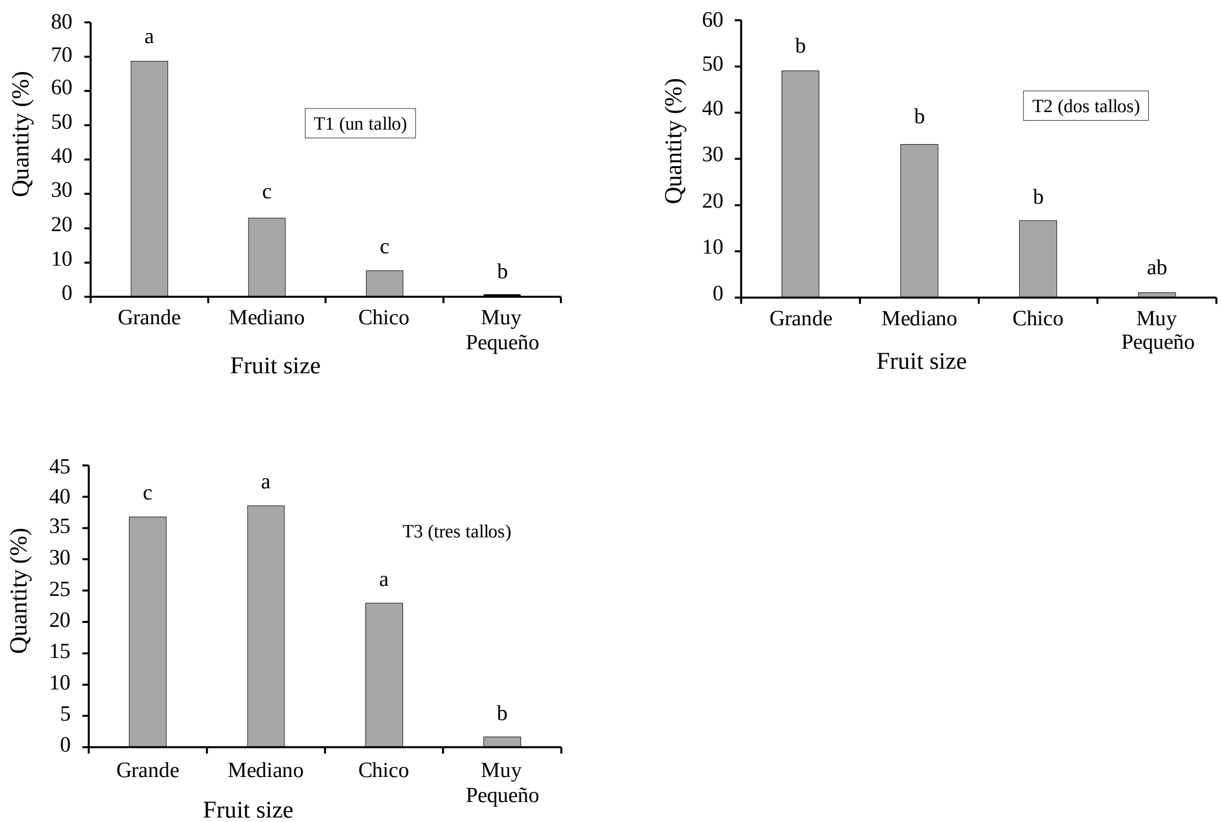

Figure 1. Classification of fruit size in the three treatments.

Tomato quality response variables

The results of the total soluble solids (ºBrix) were found to be that T3 (three stems) in the secondary stem 1 had the highest value with 4.6, 4.65 and 4.83 for the 1st, 5th and 10th clusters, respectively. No significant statistical differences were found in the values of ºBrix in the three treatments or in the clusters Table 3. The results of this work are similar to that reported by Casierra-Posada and Aguilar-Aventaño (2008), in tomato, of 4 ºBrix grown under greenhouse conditions.

Renquist and Reld (1998), mentions that when the fruits have very low total soluble solids, it is because they are harvested very early, without reaching their degree of development; these authors explain the behavior of the tomatoes in some kind of dilution, by which water intake during the development of the fruit exceeds the production of sugars and organic acids.

Table 3. Results of total soluble solids (ºBrix) in the three treatments.

Clusters	T1 (one stem)	T2 (two stems)		T3 (three stems)		
	Main stem	Main stem	Main stem	Main stem	Secondary stem 1	Secondary stem 2
1st cluster	4.5 a	4.15 a	4.4 a	4.13 a	4.6 a	4.2 a
5th cluster	4.65 a	4.5 a	4.53 a	4.68 a	4.65 a	4.23 a
10th cluster	4.58 a	4.43 a	4.6 a	4.93 a	4.83 a	4.28 a

It was observed that carbohydrates, as shown in Table 3, underwent biochemical changes by increasing the number of stems per plant, since the degradation of the polysaccharides of cell membranes, made an important contribution to the increase in the content of sugars is why the smaller fruits that are produced in T3 (three stems) presented better flavor and vitamin C content and are used mainly for preparation of puree and sauce.

For the firmness variable, T1 presented the highest value with 4.7, 4.43 and 475 in the 1st, 5th and 10th clusters, respectively. Due to the fact that this treatment had a lower leaf area index, the rays of solar radiation reached to the place where the fruits were, which is why they developed a thicker and stronger cuticle to protect the direct sun damage. In addition, protection of the developed cuticle served the fruits to increase their shelf life. In contrast, T3 presented its thinnest cuticle, because its leaf area index was greater than 6, protecting the entry of direct solar rays towards the fruits (Table 4). The result obtained in this work is similar to that reported by Casierra-Posada and Aguilar-Aventaño (2008).

Table 4. Result of the variable firmness obtained in the three treatments.

Cluster	T1 (one stem)	T2 (two stems)		T3 (three stems)		
	Main stem	Main stem	Main stem	Main stem	Secondary stem 1	Secondary stem 2
1st cluster	4.7 a	4.7 a	4.4 a	5.18 a	3.9 a	3.95 a
5th cluster	4.43 a	4.1 a	4.19 a	3.24 b	3.68 a	3.84 a
10th cluster	4.75 a	1.43 b	1.56 b	1.54 b	1.71 b	2.93 b

Tomato fruits are composed predominantly of parenchyma cells and microfibrils of cells suspended in a matrix of glycoproteins, water, pectin and hemicellulose polysaccharides (Scheible and Pauly, 2004). These compounds give consistency to the tissues and thereby acquire a greater resistance to the penetrometer; therefore, when the fruits are harvested in early degrees of maturation, the enzymatic activity that denatures the compounds that give rigidity to the fruits is lower than in those fruits harvested in late stages of development.

Total soluble solids- titratable acidity ratio: (Ballinger and Maness, 1970, Marshall and Spiers, 2002), found that a low ratio of total soluble solids/titratable acidity (SST/AT) is associated with low fruit quality, which it is related to weather variables such as cloudy days, excess radiation, temperature and high fruit transpiration.

In this work an average SST/AT ratio of 10.57, 9.98 and 11.29 was found for T1, T2 and T3, which are the values suitable for tomato harvesting since it allows to lengthen shelf life, a variable that is directly related to firmness of the fruit (Table 5). When the fruits have a firmness value of 4.5, their shelf life can range between 15 and 25 days at room temperature of 18 ºC. The results obtained in this work are similar to those reported by San Martín-Hernández *et al*. (2012) of 11.66 in tomato grown in hydroponics under protected conditions in different granulometry of tezontle as substrate.

Table 5. Results of total soluble solids-titratable acidity content in the tomato fruit juice for the three treatments.

Cluster	T1 (one stem)	T2 (two stems)		T3 (three stems)		
	Main stem	Main stem	Main stem	Main stem	Secondary stem 1	Secondary stem 2
1st cluster	11.18	10.07	10.5	9.99	12.3	13.37
5th cluster	11.52	9.23	10.49	11.7	12.2	12.34
10th cluster	9	9.74	9.84	10.51	9.83	9.41

Some researchers have suggested that SST/AT is important to define quality differences between varieties, others indicate that the quality of the fruits can be improved by increasing the total content of sugars and acids. The best way to define the maturity index in a fruit is by estimating the total soluble solids-titratable acidity ratio, this parameter indicates the content of sugars in relation to the lower amount of acidity present in the fruit (Kushman and Ballinger 1967).

Galleta *et al*. (1970) mentions that the SST/AT ratio is a parameter that determines the resistance of the fruit to detach from the plant, as long as this characteristic is not taken in hours of high temperature or luminous intensity. An adequate ratio of total soluble solids-titratable acidity is a preponderant measure that is intimately related to the quality of the fruit to be transported to great distances (Kushman and Ballinger, 1970).

Regarding vitamin C, it was found that T1 presented 18.38 mg 100 g-1 of vitamin C content in the 1st cluster, in the 5th cluster, T2 presented 17.78 mg 100 g^{-1} and in the 10th cluster, T3 presented the highest Vitamin C content with 18.47 mg 100 g^{-1}. Significant statistical differences were found in the mean values of vitamin C in the clusters (Figure 2). These results are similar to that reported by Ceballos-Aguirre *et al*. (2012), in fruits of cherry type L., cultivated in field with values from 29 to 85 mg 100 g^{-1}.

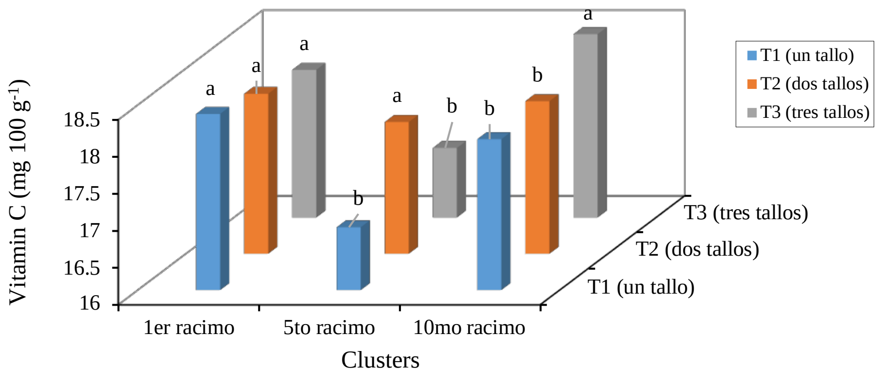

Figure 2. Content of vitamin C (ascorbic acid) in the juice of tomato fruits in the three treatments.

The disadvantage of T3 is that only 37% of the fruits were large for export, 63% were medium-sized fruits, small and very small. The advantage from the nutritional point of view for humans is 63% of the fruits that were smaller had higher vitamin C content. End consumers prefer this size for fresh consumption such as smoothies, salary preparation, as a condiment (puree), since for them these fruits have better aroma and flavor. Finally, all the fruits produced by the plant are used and waste is avoided because it is smaller.

For pH, T1 presented the highest value in the 10th cluster of 4.47 compared to the T3 that presented the same value of 4.4 (Figure 3). These data are similar to that reported by Gomes and Camelo (2002), in tomato with pH 4.36. This implies that the fruits harvested before ripening fail to perform the biochemical processes that lead to organic acids being transformed into other compounds that determine the flavor and aroma of the fruits. Significant statistical differences were found in the pH values between the clusters.

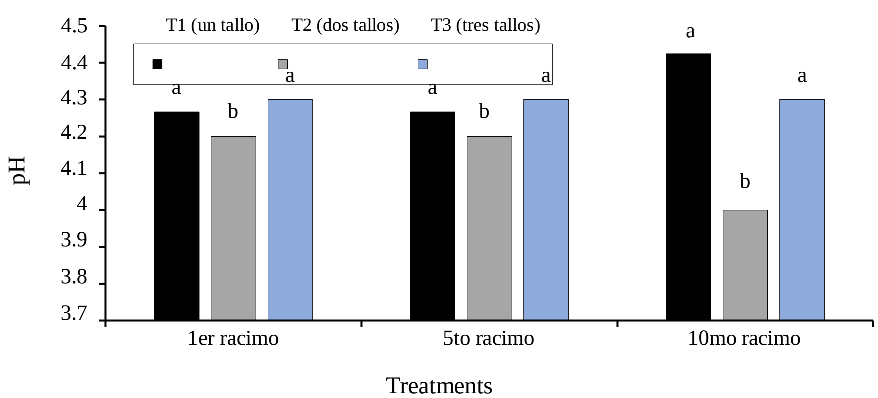

Figure 3. pH values in the juice of tomato fruits in the three treatments.

For the variable titratable acidity, the highest value was presented in the T1 with 0.5% in the 10th cluster, compared to the T3 that presented the lowest value of 0.38% in the 5th cluster. No significant statistical differences were found in the values (%) of citric acid between the clusters, nor in the three treatments (Figure 4). Results similar to those found in the present experiment were reported by Gomes and Camelo (2002), in tomatoes stored in controlled atmospheres of 0.45%.

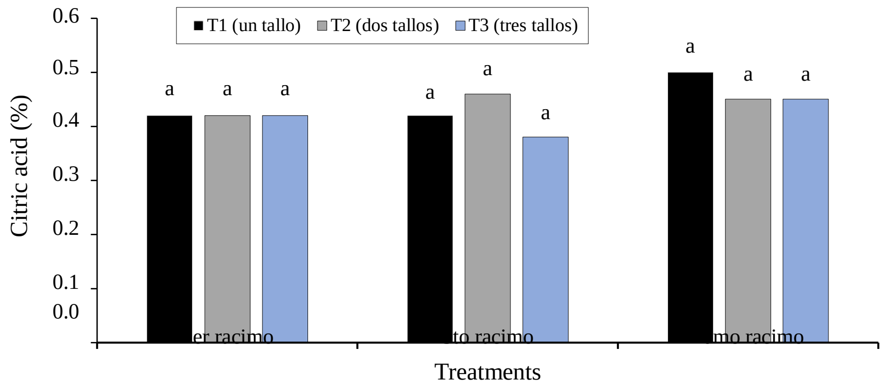

Figure 4. Titratable acidity, expressed as the percentage of citric acid in the juice in the three treatments.

Performance per plant

The yield obtained per plant for each of the treatments, the highest value was obtained in T1, with 6.55 kg pl^{-1}, followed by T2, with 5.91 kg pl^{-1} and the lowest was T3, with 5.45 kg pl^{-1}. The data obtained in this work are similar to those reported by Flores *et al*. (2007), of 4.65 kg pl^{-1} (20 kg m^{-2}) in tomato saladette, tequila variety with planting density of 4.3 pl m^{-2} with the same geometric characteristics of the greenhouse, same weather conditions and irrigation management and nutrition.

Conclusions

Regarding the quality variables, total soluble solids and pH increased with the increase in the number of stems per plant compared with the firmness that decreased. In the 10th cluster of T3 (three stems) there was a higher content of vitamin C. In addition, a positive relation was found between total soluble solids/titratable acidity that indicates fruits of good quality and greater resistance of the fruits to detach from the plant. The yield obtained was 6.55, 5.91 and 5.45 kg pl^{-1} for T1, T2 and T3 per plant, respectively. The T1 was better in fruit size with 69, 23, 8 and 1% of large, medium, small and very small category per plant, respectively. Additionally it was observed that, when increasing the number of stems per plant, the total number of fruits increases; however, the size decreases drastically, that is why producers are recommended to use T1 to produce large-sized fruits for export purposes and T2 to produce fruits for domestic consumption (tianguis, supermarkets, etc). In addition, these two treatments have lower demand for labor, better control of pests and diseases and easy agronomic management.

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