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Article

Productivity of six varieties of Saladette tomato under greenhouse conditions in Ojocaliente, Zacatecas

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Abstract

Tomatoes are one of the most economically important horticultural crops worldwide, and Mexico stands out as one of the leading producers. Due to their relevance, it is essential to carry out studies that allow us to know the yield of the various varieties and improve decision-making by producers. The study aimed to characterize six varieties of Saladette tomatoes and evaluate their productivity under greenhouse conditions in the municipality of Ojocaliente, Zacatecas, from May to August 2023. Fruit quality and quantity variables, including size (equatorial length and width), fruit weight, and number of harvestable fruits, were measured during the first five fruit cuts. The results showed that variety 7815 presented the highest averages in length (79.43 mm), width (59.04 mm), and weight (158.14 g) of the fruit, followed by the Lubino variety, with 76.67 mm, 54.67 mm, and 129.1 g, respectively. On the other hand, the Cedros variety presented the lowest values in these variables, with 67.08 mm, 49.17 mm, and 93.56 g, respectively. Regarding the number of harvestable fruits, no significant differences were observed between the varieties studied. These results provide valuable information that can help producers in the selection of the most suitable variety according to the desired characteristics of the fruit and the needs of the market.

Keywords:

Solanum lycopersicum, fruit quality and quantity, protected agriculture.

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Introduction

Tomatoes (*Solanum lycopersicum* L.) are a crop of great importance both globally and nationally and stand out for their high consumption, large harvested area, and significant economic value. Their economic importance is primarily due to the generation of numerous direct and indirect jobs, especially in production under protected conditions, an agricultural modality that has shown sustained growth in recent years (Padilla-Bernal *et al*., 2008; Mejía-Betancourt *et al*., 2023).

In 2023, global tomato production reached approximately 192.3 million tons, with Mexico ranking seventh globally with 4.3 million tons. Mexico is one of the leading exporters of this crop (FAOSTAT, 2023).

Tomatoes are produced in practically all states, but eight states account for 72% of the national production. The state of Zacatecas is one of the largest tomato producers in the country, producing 4.74% of the national production, with a production of 193 363 t in 2017 (Montaño-Méndez *et al*., 2021). In Zacatecas, tomato production has grown significantly in recent years, mainly attributable to the climatic and geographical conditions of the region.

The temperate and arid climate, combined with high solar radiation, present in some areas of Zacatecas, such as the municipality of Ojocaliente, favors the implementation of protected agriculture systems, such as greenhouses and shade netting. This system allows tomato production most of the year (Padilla-Bernal *et al*., 2008).

Tomatoes are grown in different low- to high-tech protected systems and can be grown using soil or substrates (Padilla-Bernal *et al*., 2008; Sánchez-Del Castillo *et al*., 2017). In tomato crops under greenhouse conditions, 2 to 3 plants m^{-2} are established. Thanks to the controlled environment offered by this protected system, crop productivity is higher, allowing at least 20 bunches per plant to be harvested throughout a cycle that extends over most of the year (Sánchez-Del Castillo *et al*., 2017; Mejía-Betancourt *et al*., 2023).

Therefore, production costs become high, since, in some cases, sophisticated cultivation systems are used, such as hydroponics (Padilla-Bernal *et al*., 2008). In Mexico, Saladette tomatoes are one of the most widely used for the national and international market (Cih-Dzul *et al*., 2011; Balbuena-Mascada *et al*., 2023). This crop presents variations in fruit quality between genetic lines, which affects crop productivity (Balbuena-Mascada *et al*., 2023).

The correct selection of tomato varieties represents an effective solution to improve fruit quantity and quality. Nevertheless, there is still little research on their yield under greenhouse conditions (García-León *et al*., 2018). It is crucial to evaluate different varieties and use new, more productive materials from various improvement programs. Before using new varieties, it is necessary to test them to select those that best adapt to the area and offer greater productivity (Rodríguez-Burgos *et al*., 2011).

There is a wide diversity of tomato varieties and genotypes that have been used in agriculture (Santiago *et al*., 1998; Monge-Pérez, 2014; García-León *et al*., 2018). This diversity makes it necessary to have information that enables us to select the ones that work best according to the producer's needs. There is currently no published information on the productivity of Saladette tomato varieties grown under greenhouse conditions in the Zacatecas region.

Therefore, it is necessary to carry out studies that generate useful data to support tomato production in the region, improve the productivity of the crop, and diversify the supply in the market. Having information about the varieties of Saladette tomatoes that exist in the region is of great importance for producers, since it allows them to choose the variety that provides greater productivity, better fruit quality, and better adaptation to specific production conditions.

Therefore, the present work aims to characterize the fruit of six varieties of Saladette tomato by evaluating their productivity under greenhouse conditions. Under the hypothesis that there are significant differences between the varieties evaluated.

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Materials and methods

The research was carried out in greenhouse conditions from May to August 2023. The greenhouse is located in the municipality of Ojocaliente, Zacatecas, 22° 36' 10" north latitude and 102° 14' 31" west longitude, at 2 079 masl (Figure 1) in the facilities of a local producer.

Figure 1. Study area located in Ojocaliente, Zacatecas, Mexico.

Fruits of Saladette tomato (*Solanum lycopersicum*) plants of the varieties Lubino, Yecora, Cedars, Canelo, Azores, and 7815 (the latter variety is not yet on the market) were evaluated. The study was conducted in a 1/4 ha greenhouse, without a temperature control system, with manually operated side windows. Cultivation beds of 90 cm wide, 40 cm long, and 36 cm between plants were used, reaching a density of 28 600 plants ha^{-1}. The substrate used was a soil with a loam texture present in the area.

The transplant was carried out on April 12, 2023, using black-white plastic mulch and a drip irrigation system. The six varieties were distributed in three sections of the greenhouse, with one variety per cultivation bed in each section. During the crop cycle, the temperature ranged from 11.01 °C (minimum) to 39.8 °C (maximum), with a relative humidity between 30% and 90%.

To assess productivity, 10 plants were randomly selected along the cultivation bed, excluding those located on the edges to avoid the edge effect. Each plant was identified by a tape attached to the training string. This procedure was repeated for the six varieties evaluated. During the first five cuts, the number of plants with harvestable fruits and the number of fruits per plant for each variety were recorded. In addition, the size of the fruits (equatorial length and diameter) was measured with a HONGHC digital vernier, and their weight was determined using a Yiwuxuefu XT00109 scale.

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Statistical analysis

The hypotheses of differences in the length, width, weight, and number of fruits harvested from the six varieties of Saladette tomato were tested with a one-way analysis of variance (Anova) with a α= 0.05 and a 95% confidence interval using the R software version 4.2.1 (R Core Team, 2020) with the stats v. 3.6.2 package (Chambers *et al*., 1992). The effect size was analyzed with the omega-squared estimator (ω^2) (Field, 2013). In order to illustrate the *post hoc* tests, the ggstatsplot v. 0.12.1 package with the ggbetweenstats function was used (Patil, 2021). To achieve this, comparisons of trimmed means were used according to Yuen (1974) criteria.

Bonferroni *p*- value adjustment was used to correct for the effects of multiple comparisons and avoid making the type I error (Wilcox, 2022). The normality of the residuals and the homoscedasticity of variances were analyzed using the Kolmogorov-Smirnov test with the Lilliefors correction (Gross and Ligges, 2015) and the Levene test using the car v. 3.1-1 package (Fox and Weisberg, 2019).

Results and discussion

Morphological analysis of the fruit

The varieties 7815, Lubino, and Yecora stood out for presenting the highest averages in the morphological characteristics evaluated. In particular, variety 7815 showed the highest values in fruit length, width, and weight, with averages of 79.43 mm, 59.04 mm, and 158.14 g, respectively. In contrast, the Cedros variety presented the lowest averages in these traits, with values of 67.08 mm, 49.17 mm, and 93.56 g, respectively.

Regarding the consistency of the morphological traits, the Yecora variety showed the least dispersion in the data, with standard deviations of 6.17 mm in length, 4.75 mm in width, and 29.55 g in weight of fruits. This indicates that Yecora has a greater uniformity in its fruits. In contrast, the varieties Lubino, Azores, and 7815 showed greater variability in their morphological characteristics. For example, Lubino presented a standard deviation of 11.29 mm in fruit length, Azores of 7.69 mm in fruit width, and 7815 of 47.94 g in fruit weight (Table 1).

Table 1. Descriptive statistics of the morphometric variables of fruits measured in six varieties of Saladette tomato.

Variety	n	Average	Min	Q1	Median	Q3	Max
			Length (mm)				
7815	35	79.43 ±10.29	39.65	75.96	81.85	85.45	94.34
Lubino	36	76.67 ±11.29	35.88	74.92	78.98	83.43	91.57
Yecora	34	75.05 ±6.17	56.06	71.1	75.63	79.26	84.23
Canelo	38	71.62 ±10.73	37.14	67.49	74.08	79.37	86.56
Azores	41	68.15 ±10.54	36.9	66.28	71.7	74.07	84.18
Cedros	35	67.08 ±9.58	40.3	63.13	69.95	73.54	81.24
			Width (mm)				
7815	35	59.04 ±7.34	42.46	53.79	60.47	64.86	73.82
Yecora	34	55.54 ±4.75	45.6	52.67	55.2	58.77	67.67
Lubino	36	54.67 ±7.4	32.28	54.5	57.35	59.33	62.83
Canelo	38	52.73 ±7.58	30.6	50.69	54.7	57.81	62.91
Azores	41	51.89 ±7.69	32.08	49.08	54.18	57.47	61.99
Cedros	35	49.17 ±6.65	34.64	45.22	50.23	54.02	59.33
			Weight (g)				
7815	35	158.14 ±47.94	34	131.5	159	187.25	267
Lubino	36	129.1 ±37.4	18	126.5	139.75	152.12	165.5
Yecora	34	126.21 ±29.55	60	113.5	123	140	200

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Variety	n	Average	Min	Q1	Median	Q3	Max
Canelo	38	113.05 ±39.21	19	93.25	119.5	146.88	170
Azores	41	104.09 ±35.06	18	89	115	129	163
Cedros	35	93.56 ±31.41	27	72.75	97	116.25	147.5

Q1= first quartile; Q3= third quartile; Min= minimum values of the independent variable; Max= maximum values of the independent variable; pverage ± standard deviation.

The analysis of variance (Anova) showed statistically significant differences between tomato varieties in terms of fruit length, width and weight (Table 2). It was also shown that tomato varieties had a greater effect on fruit weight ($\omega^2=0.22$) compared to fruit width ($\omega^2=0.14$). These ω^2 values indicate a moderate to large effect based on standard interpretation guidelines. Therefore, it is concluded that the variety considerably influences the morphology of the fruit, specifically in the length, width and weight of Saladette tomato (Field, 2013).

Table 2. Anova results on the effect of varieties using fruit length, width, and weight as criteria.

Response variable	F_{gl}	P_{valor}	ω^2	LL ω^2	UL ω^2
Length	$F_{5,213}$= 8.7	0.001	0.15	0.07	1
Width	$F_{5,213}$= 8.2	0.001	0.14	0.06	1
Weight	$F_{5,213}$= 13.25	0.001	0.22	0.13	1

LL and UL represent the confidence intervals of the lower and upper limits of ω^2.

Figures 2, 3, and 4 show the result of the statistical significance of multiple comparisons. According to Figure 2, of the 15 paired comparisons made, 7 were statistically significant, indicating differences in fruit length between some varieties. Specifically, variety 7815 presented the longest fruit length, reaching 81.36 mm, while the Cedros variety presented the shortest length, with 69.03 mm. In addition, the Yecora variety stood out for its lower dispersion in the data, suggesting a greater uniformity in fruit length compared to the other varieties.

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Figure 2. *Post hoc* test with trimmed means and Bonferroni correction for multiple comparisons. The top bars represent statistical significance.

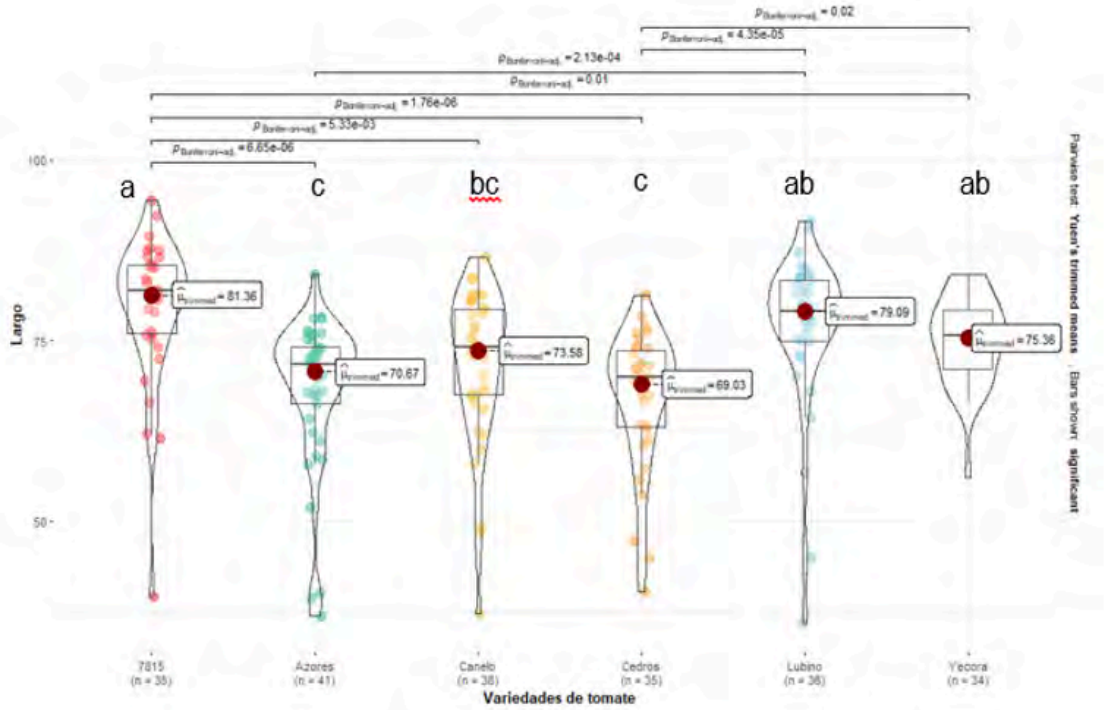

Figure 3. *Post hoc* test with trimmed means and Bonferroni correction for multiple comparisons in fruit width. The top bars represent statistical significance.

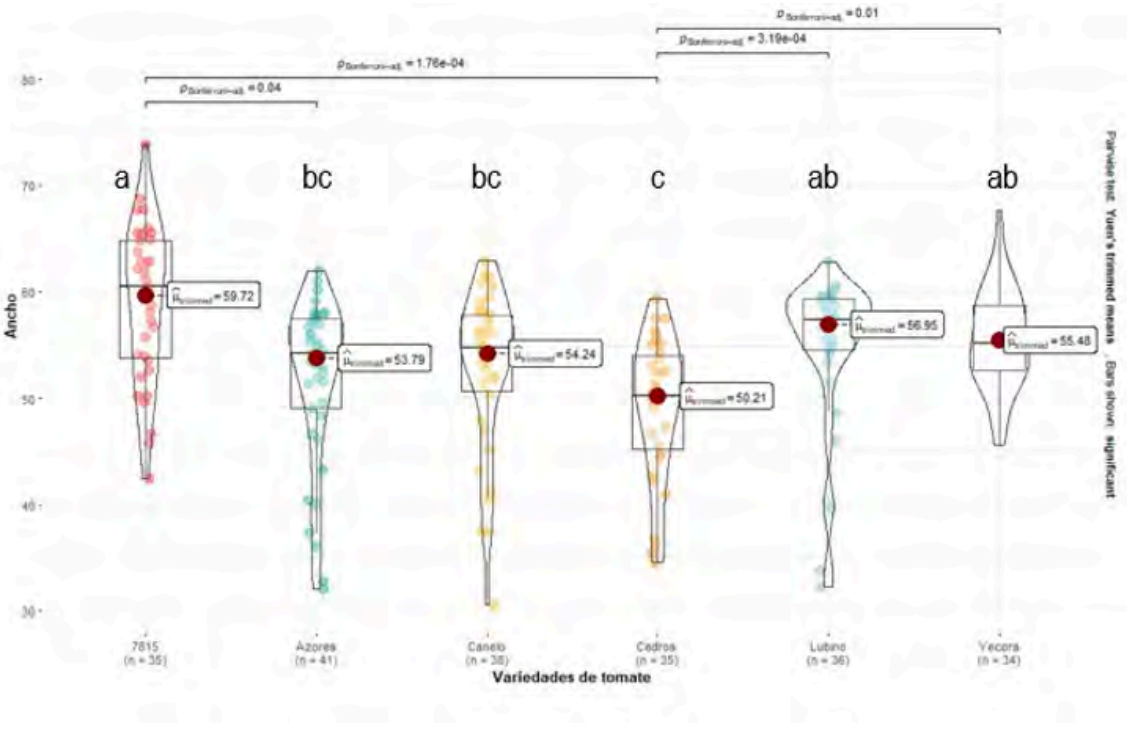

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Figure 4. *Post hoc* test with trimmed means and Bonferroni correction for multiple comparisons in fruit weight. The top bars represent statistical significance.

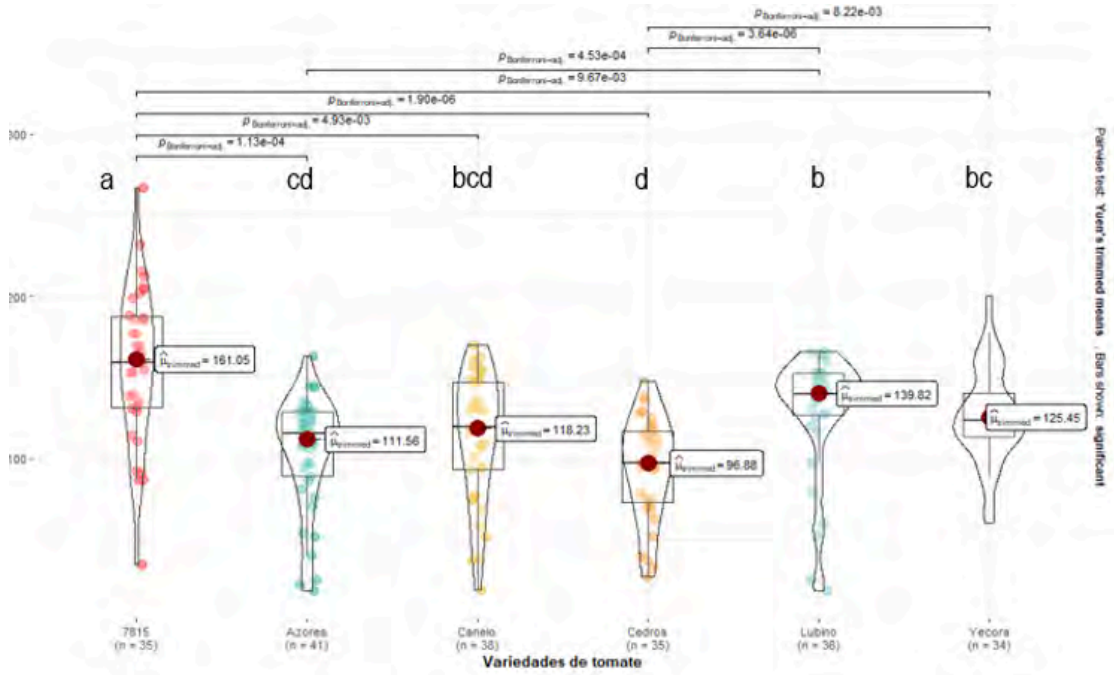

Figure 3 showed that variety 7815 had the largest fruit dimensions, with an average width of 59.72 mm. In contrast, the Cedros variety presented the smallest dimensions in the same parameter, reaching a width of 50.21 mm. Likewise, the descriptive analyses shown in Table 2 indicate that the Yecora variety stands out for its greater uniformity in fruit length.

Figure 4 shows that variety 7815 presented the largest fruits, with an average weight of 161.05 g. In contrast, the Cedros variety presented smaller fruits, with an average weight of 96.88 g. In addition, according to the descriptive analyses of Table 2, the Yecora variety stood out for its greater uniformity in fruit length.

The size and weight of the fruits vary between the different varieties studied (Rodríguez-Burgos *et al*., 2011). The variability in the traits and quality of the fruit can be attributed both to the specific genetics of each variety and to the production conditions, which directly influence its development (Rodríguez-Burgos *et al*., 2011; Monge-Pérez, 2014; García-León *et al*., 2018). The data obtained on the size (equatorial and polar diameter) of the fruits were higher than those reported in another study carried out on Saladette tomatoes, Sahel variety.

This study mentions diameters of 4.1-4.7 cm and 4.8-5.9 cm for equatorial and polar diameters, respectively (González *et al*., 2016). Regarding fruit weight, four of the varieties evaluated in this study exceeded the values reported by the Yaqui variety, which weighted between 102.7 and 112 g per fruit (Bugarin-Montoya *et al*., 2002). It is also superior to various lines analyzed in other studies, which presented values less than 144.1 g (Balbuena-Mascada *et al*., 2023).

Morphological variables expressed in weight, size and number of fruits per plant are important characteristics for knowing crop yield, as well as for selection in genetic improvement and variety selection programs in the industry (Balbuena-Mascada *et al*., 2023). It should be noted that quality parameters are usually variable due to the differences between tomato types, varieties, and cultivation conditions.

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Various studies have analyzed different tomato varieties, highlighting their morphological and agronomic traits. For example, the round tomato is characterized by large, rounded fruits with a great weight. In contrast, native tomatoes have a wide morphological diversity. On the other hand, the Saladette tomato, where various varieties have been mentioned, presents variation in the morphology of the harvested fruit (Maldonado-Peralta *et al*., 2016; García-León *et al*., 2018; Maldonado-Peralta *et al*., 2023; Balbuena-Mascada *et al*., 2023).

Due to the large number of lines and varieties of Saladette tomatoes, it is advisable to carry out more studies on their productivity and fruit quality in different regions of Mexico, since they are one of the most consumed nationally (Cih-Dzul *et al*., 2011; Balbuena-Mascada *et al*., 2023).

Little has been reported regarding uniformity in the fruit size of tomato crops (Luna-Fletes *et al*., 2018). In general, it is only mentioned that better quality and homogeneity of fruits are obtained under controlled conditions (Maldonado-Peralta *et al*., 2023). The results show that the genetics of variety is another factor that can affect the dimensions of the fruit and its uniformity (Balbuena-Mascada *et al*., 2023).

Productivity by plant

No significant differences ($p > 0.05$) were observed in productivity measured as the number of fruits harvested per cut. On average, the 10 plants evaluated produced between 12.6 and 16.2 tomatoes per cut. Throughout the five cuts made, variations were recorded in the number of fruits harvested per plant, with a range of 1.14 to 3.33 fruits per plant. In each cut, fruits were harvested from between five and nine plants of the ten evaluated (Table 3).

Table 3. Produc on per plant in the five cuts.

Variety	Cut 1		Cut 2		Cut 3		Cut 4		Cut 5		Average of tomatoes per cut
	PF	AFP	PF	AFP	PF	AFP	PF	AFP	PF	AFP	
7815	5	2 ±1	9	2 ±0.71	7	1.71 ±0.76	8	1.75 ±0.46	6	1.5 ±0.84	12.6 ±3.58
Azores	6	1.67 ±1.03	9	2.11 ±0.78	9	1.89 ±0.6	10	1.9 ±0.88	7	2.29 ±0.95	16.2 ±3.7
Canelo	7	1.14 ±0.38	9	2.78 ±0.97	9	1.78 ±1.09	6	1.5 ±0.55	7	2.14 ±1.07	14.6 ±6.8
Cedros	8	2.5 ±0.76	10	2.4 ±0.84	7	1.29 ±0.49	5	1.6 ±0.55	5	1.8 ±0.84	14 ±7.45
Lubino	6	1.83 ±0.75	7	2.14 ±0.38	9	1.67 ±0.87	9	2.22 ±0.97	5	1.2 ±0.45	13.4 ±5.22
Yecora	6	1.67 ±0.52	9	3.33 ±2.18	7	2 ±1	7	2.14 ±1.21	5	1.8 ±0.45	15.6 ±8.44

PF= plants with harvestable fruits; AFP= average fruits harvested per plant ±SD.

The average number of tomatoes harvested per plant in each cut showed no statistically significant differences. The above coincides with what was reported by Santiago *et al*. (1998), who evaluated hybrids and varieties of tomato and found no significant differences in the amount of harvestable fruits. Both the number of fruits and the variables of quality are affected by management factors and conditions of production, in addition to the variation in genetics between varieties and accessions (Rodríguez-Burgos *et al*., 2011; Monge-Pérez, 2014; García-León *et al*., 2018).

The reason that no differences were found is probably because the number of fruits is influenced by morphological characteristics of the plants, including the type of inflorescence and the number of flowers per cluster (Rivas *et al*., 2012). The results show that there are differences between varieties, so it is advisable to continue with this type of work that provides us with information on quality and production, considering that the tomato industry in protected agriculture in the country and the state of Zacatecas has been increasing (Padilla-Bernal *et al*., 2008). Having this type of information will be helpful to producers when selecting the most suitable variety for the semi-arid region of Zacatecas and surrounding areas under greenhouse conditions.

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Conclusions

The tomato varieties 7815 and Lubino stood out for their fruit quality under greenhouse conditions, showing the best values in weight and size. In contrast, Cedros presented a lower quality, with significantly lower values in the variables evaluated compared to the other varieties. It should be noted that the number of harvestable fruits did not show significant differences between the six varieties studied.

It is recommended to continue with studies on tomato quality and productivity, especially in the context of protected agriculture, which has shown sustained growth both at the state and regional levels. This crop is key to the local economy, as it represents a significant source of income and jobs for the state of Zacatecas. Having updated information on the best tomato varieties will allow a better use of the resource and improved yields. In addition, it is pertinent to expand research to other tomato varieties, as their diversification can strengthen the competitiveness of the sector and better respond to market demands.

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