Article

Sowing density of four roselle varieties for the dry tropics of the state of Michoacán

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Abstract

The objective was to evaluate the effect of the yield of four roselle varieties sown in two sowing densities: 8 265 (2) and 13 889 (1) plants ha^{-1}, under conditions of dry tropics in Michoacán. The experimental design was in random complete blocks with a 2 x 4 factorial arrangement, two sowing densities (factor a) and four varieties (factor b), with nine repetitions per treatment. The following variables were recorded: plant height (PHE), diameter at the base of the stem (DBS), number of branches (NB), fresh weight (FW) and dry weight (DW) per plant, and fresh (FRESY) and dry (DRYY) yield per hectare. An Anova (α= 0.05) and a mean comparison test (Tukey, 0.05) were performed to determine the effect of the factors and their interactions (a∗b), correlation analysis was also performed between the recorded variables. Significant differences were found within factor a ($p\leq 0.05$) for the variable PHE, in density 1, PHE was 217 cm and in density 2 it was 197 cm. In factor b, highly significant differences were detected ($p\leq 0.05$), the Patriota variety reached the highest PHE with 232 cm. No significant differences were identified for the variables DBS, NB and FW, DW, in both factors or their interaction. Regarding the yield of the dry weight of the calyxes, in the factor densities, there were significant differences ($p\leq 0.05$), density 2 reached the highest DRYY with 573.3 kg ha^{-1}. The variables FW and DW were positively correlated with DRYY (r= 0.82).

Keywords: *Hibiscus sabdariffa* L., agronomic management, crop management, rainfed agriculture, yield.

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Introduction

In the state of Michoacán, 1 780 ha are sown with roselle (*Hibiscus sabdariffa* L.), and the most important producing localities of this crop are La Huacana with 61.1% of the total state production, with an average yield of 570 kg ha^{-1}, followed by Churumuco, which contributes 16.7%, and Aquila with 16.4% of the state production (SIAP-SADER, 2022). The yields obtained in the dry tropics producing region of Michoacán are considered low and are due to the scarce technology used in the production systems. Although it is a crop suitable for the agroclimatic conditions of the region, it is cultivated marginally and hence its low profitability (Burgos, 2019).

Sowing density is a factor of utmost importance that must be considered in the management of a crop and there are no studies reported in the country for roselle. The few studies regarding population density in roselle indicate that there is variation in the weight of calyxes obtained with different sowing densities; Babatunde *et al*. (2002) identified that the separation between roselle plants correlates positively with the height of the plant, diameter of the crown, number of branches, weight of the calyxes and weight of the seeds, this is because the plant has a greater opportunity to produce branches.

For their part, Terán and Soto (2004) evaluated six sowing distances, where yields behaved in correspondence with sowing densities, they obtained 7.5 t ha^{-1} of fresh calyxes in the highest density (13 888 plants ha^{-1}) and 4.5 t ha^{-1} in the smallest density (8 333 plants ha^{-1}). In addition, the yield of dehydrated calyx per plant was lower in high population densities (10 000 plants ha^{-1}); however, their yield increases due to the higher number of plants per unit area. Densities of 13 888 plants ha^{-1} allow obtaining 87% of dry calyxes per hectare, compared to a sowing density of 8 333 plants ha^{-1}.

Urbina (2009) mentions that the sowing distance is 1.3 and 0.9 m. On the other hand, Hidalgo (2013) recommends 1 m x 0.8 m, with three seeds per plant. Carrascal *et al*. (2013) with respect to the number of calyxes produced, the best results occurred at distances of 1.2 x 1.2 m with 240 calyxes per plant, followed by 1 x 1.2 m with 152 calyxes $plant^{-1}$; in addition, the lowest average weight occurred with a spacing of 1 x 0.8 m, with 10.6 g $plant^{-1}$, followed by 1 x 1 m and 0.5 x 1 m with 11 g $plant^{-1}$ on average and the best average was exhibited by the spacing 1.2 x 1.2 m with 11.6 g.

Other authors such as González and Chamorro (2017) evaluated the effect of population density on the growth and yield of roselle, with the Reina Salvadoreña variety, and found that the density of 4 444 plants ha^{-1} (1.5 x 1.5 m) favored the growth of the basal diameter, crown diameter and greater number of calyxes, but not the height and number of branches per plant. In addition, they mention that, in high densities (10 000 plants ha^{-1}), lower average values of the basal diameter and crown are obtained in relation to the low densities (4 444 plants ha^{-1}), where the plants have more space. Based on the above, the objective of the present study was to evaluate the yield of four roselle varieties sown in two sowing densities under conditions of the dry tropics of the state of Michoacán (El Naim *et al*., 2012).

Materials and methods

Study area

The study was carried out in the locality of ‘El Sifón’, municipality of Gabriel Zamora, Michoacán, which is located at the coordinates 19° 10’ 27.458” north latitude and 101° 55’ 59.005” west longitude, at an average altitude of 439.95 m, the region to which it belongs is part of the Sierra Madre del Sur of the state (INAFED, 2019). The climate is of the Awo (w) type, warm subhumid with rains in summer, Köppen modified by García (2004), the average annual rainfall is from 800 to 1 000 mm, with a percentage of winter rainfall less than 5 °C and temperatures that range from 14 to 36 °C. The soil is pelic Vertisol, of calcareous origin, clayey and with a depth greater than 1 m, content of organic matter of 1.64%, pH of 7.58 and with loamy-clayey-sandy texture (20% silt, 25.4% clay and 54.6% sand), with 1.99% of organic matter. The terrain is slightly flat, and the vegetation is mainly made up of tropical deciduous forest (INAFED, 2019).

Characterization of varieties

The varieties Mulata, Estrella Costeña and Patriota were characterized in the Iguala-INIFAP Experimental Field. Mulata (JAM-007-231117): 5-6.5 cm calyx length, 4 to 5 cm calyx width, 110 days to flowering (sowing in June), 145 days to harvest, 150-175 cm plant height, 6 branches plant^{-1}, 900-1 000 kg ha^{-1} dry calyx yield, high antioxidant content and sweet taste. Estrella Costeña (JAM-05-231117): 8-9.5 cm calyx length, 8.5 to 9.5 cm calyx width, 120 days to flowering (sowing in June), 150 days to harvest, 170-190 cm plant height, 5 branches plant^{-1}, 1 300 kg ha^{-1} dry calyx yield, high antioxidant content and sweet taste. Patriota (JAM-008-231117): 6.5 to 8 cm calyx length, 5.5 to 7 cm calyx width, 120 days to flowering (sowing in June), 165 days to harvest, 170-200 cm plant height, 5 branches plant^{-1}, 1 000 kg ha^{-1} dry calyx yield, high antioxidant content and sweet taste.

Estrella (control): 5.7 cm calyx length, 2.9 cm calyx width, 102 days to flowering, (sowing in July), 165 days to harvest, 192-200 cm plant height, 12 branches plant^{-1}, 440 kg ha^{-1} dry calyx yield, high antioxidant content and sweet taste (own characterization). According to their vegetative cycle, these varieties are considered as early (136 to 160 days from emergence to harvest) and medium early (161 to 180 days) (SAGARPA, 2012).

Experiment management

The experimental area was 1 473 m^2, where the experimental plots were located. The treatments were population density 13 889 (1) and 8 265 (2) plants ha^{-1}, which corresponds to a spacing of 0.9 m x 0.8 m and 1.1 m x 1.1 m, between plants and furrows, respectively. The following roselle varieties were evaluated: Patriota, Estrella Costeña, Mulata and Estrella (control of the region). The sowing was carried out on June 30, 2021, at the beginning of the rainy season, 10 seeds were deposited per hole at a depth of 1 cm, after the emergence of the plants, a thinning was carried out to leave one plant per point.

Due to the presence of the cutworm (*Agrotis* spp.), Cipermetrina® and Sicoro® 20 EC were applied in doses of 35 ml of product in 7 L water. Also, leaf-cutting ant (*Atta mexicana*), for its control Patrón ultra® was used at doses of 90 g, alternate applications of Siroco® in doses of 50 g anthill^{-1}, Trompa® (abamectin) and Patrón ultra (imidacloprid) applying 120 g anthill^{-1}, were also made. Slugs (*Deroceras* spp.) and *Diabrotica* spp. were also present, for both, Siroco® was applied in doses of 35 ml of product in 7 L water.

The main weeds found in the plot were: *lentejilla* (*Lepidium virginicum* L.), *mala mujer* (*Cnidoscolus urens*), *quelite* (*Amaranthus palmeri* Wats.), *chayotillo* (*Sicyos deppei*), *abrojo* (*Tribulus terrestris* L.), *panguica* (*Aldama dentata* La Llave & Lex.), *huizach*e (*Acacias* sp.) among others (Rzedowski, 2008). For their control, Fogonazo® herbicide was applied at a dose of 135 ml of product in 15 L of water. One month after sowing, it was fertilized with Sulfamin 45® (ammonium sulfate, N 21, S 24), with application of 5 g plant^{-1}. In August, weeding and hilling were carried out, in addition to manual weeding to eliminate the weeds.

Recorded variables

The following was recorded: plant height (PHE) in centimeters, measured with a metal grade rod, diameter at the base of the stem (DBS) in millimeters, measured with a Truper® digital vernier, number of branches (NB) with the direct count of each plant marked, fresh weight (FW) and dry weight (DW) of the calyxes per plant, with a Vagalbox® portable digital scale graduated in grams, the determination in fresh was made after cutting (FW) and the dry weight was obtained after drying outdoors for seven days. With the FW and DW data, the fresh (FRESY) and dry (DRYY) yields per hectare were estimated according to the density of the treatment.

Experimental design and statistical analysis

The experimental design used was in random complete blocks with a 2 x 4 factorial arrangement, two sowing densities (Factor a) and four roselle varieties (Factor b), with nine repetitions per treatment. In three furrows 10 m long and in the central furrow, nine plants per treatment were randomly selected, each roselle plant represented an experimental unit. An analysis of variance (Anova) was performed with a significance level (α= 0.05) to determine the effect of the factors and their interactions (a$*$b) on the average values of the variables recorded.

The mathematical model was $Y_{ijk}=\mu +A_i+B_j+AB_{ij}+E_{ijk}$. Where: Y_{ijk}= value of the response variable of repetition 1 of level i of A and level j of B; μ= overall mean; A_i= effect of level i of factor A (sowing density); B_j= effect of level j of factor B (variety); AB_{ij}= interaction of level i of A and level j of B; E_{ijk}= experimental error corresponding to repetition k of level i of A and j of B. When there were significant differences in the factors evaluated separately or in interaction, a mean comparison test with Tukey (α=0.05) was performed, in addition, a Pearson correlation analysis was performed between the recorded variables. Statistical analyses were performed with SAS software ver 9.4 (SAS Institute, 2013).

Results and discussion

Plant height

In the factor sowing density (a), the Anova showed highly significant differences ($p \leq 0.05$) for this variable (Table 1), the density of 13 888 plants ha^{-1} (1) was higher with an average of 217 cm, in relation to the density of 8 264 plants ha^{-1} (2), which obtained 197 cm in average of plant height (Table 2).

Table 1. Analysis of variance of the effect of sowing densities, varieties, and their interactions on roselle yield components.

Source of variation	DF	Variables						
		PHE (cm)	DBS (mm)	NB	DW (g)	FW (g)	Fresh yield (kg ha^{-1})	Dry yield (kg ha^{-1})
Density (a)	1	17.87 ***	0.0016 ns	0.56 ns	8.7E-06 ns	0.06 ns	14.38 ***	14.99 ***
Variety (b)	3	12.43 ***	0.92 ns	0.73 ns	0.76 ns	0.62 ns	0.82 ns	0.79 ns
a∗b	3	0.68 *	0.27 ns	0.22 ns	0.3 ns	0.43 ns	0.4 ns	0.62 ns

DF= degrees of freedom; PHE= plant height; DBS= diameter of the stem; NB= number of branches; ns= not significant; *= statistically significant ≤0.05, ***= statistically significant ≤0.001.

Regarding the factor varieties (b), there were highly significant differences ($p \leq 0.001$) in the Anova (Table 1), and the Tukey test ($p = 0.05$) showed that the Patriota variety reached the highest PHE with an average of 232 cm and in a second group, the varieties Mulata, Estrella Costeña and control had an average PHE of 202, 195 and 199 cm, respectively (Table 2). In the interaction of the factors a∗b, the highest PHE occurred in the density of 13 888 plants ha^{-1} and the Patriota variety with 247 cm and in the density of 8 264 plants ha^{-1} also with the Patriota variety, which reached a height of 217 cm, with statistical equality (Table 2).

Table 2. Comparison of means of the effect of sowing densities, varieties and their interactions on plant height and yield of roselle (Tukey, *p*= 0.05).

Source of variation	PHE (cm)	Fresh yield (kg ha^{-1})	Dry yield (kg ha^{-1})
Density (a)			
13 888 (1)	217.1 a	4947.6 a	573.3 a
8 264 (2)	196.8 b	2944.8 b	351.2 b
MSD	9.6	1000.4	114.58
Variety (b)			
Patriota (1)	232 a	3620.4 a	446.9 a
Mulata (2)	201.6 b	4203.3 a	485.9 a
Estrella Costeña (3)	194.9 b	4487.4 a	518.1 a
Control (4)	199.3 b	3473.7 a	399.9 a
MSD	17.92	505.8	213.98

Source of variation	PHE (cm)	Fresh yield (kg ha^{-1})	Dry yield (kg ha^{-1})
		Interaction a∗b	
1∗1	246.6 a	4752.8 a	570.9 a
1∗2	209.6 b	5092.3 a	591.1 a
1∗3	207.1 b	5871.5 a	678.9 a
1∗4	205.1 b	4073.8 a	452.1 a
2∗1	217.4 ab	2473.7 b	321.3 a
2∗2	193.6 bc	3314.4 b	379.2 a
2∗3	182.7 c	3103.3 b	357.1 a
2∗4	193.4 bc	2873.7 b	347.0 a
MSD	30.11	1695.9	359.45

PHE= total plant height, different letters in columns indicate significant differences ($p \leq 0.05$); MSD= minimum significant difference.

The differences in growth in the height of the plant are mainly due to competition for sunlight, which directly affects its production because it is a photoperiod plant, a term that is related to the response of the plant to the length of day and night (Chavarría, 2012), in addition, the shorter the distance between plants (higher sowing density), they compete for nutrients, as there is greater competition between them, which is reflected in a greater development in the height of the plants. Figure 1 shows the interaction between the factors density∗variety for PHE of roselle, where higher plant growth is observed for the Patriota variety in the density of 13 888 plants ha^{-1}.

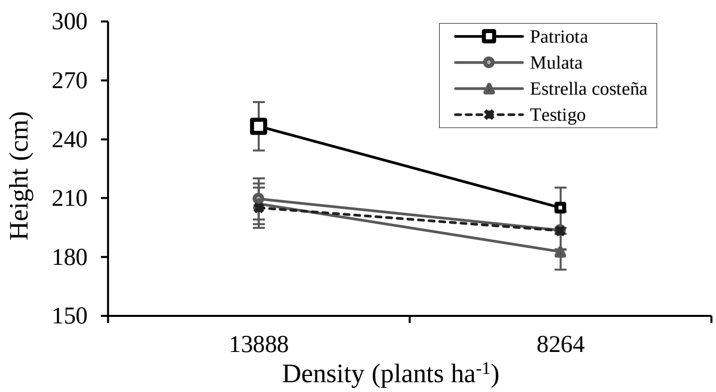

Figure 1. Interaction density∗variety on plant height growth in roselle. El Sifón, Gabriel Zamora, Michoacán.

In this regard, in Cuba, Terán and Soto (2004) found significant differences in height of roselle plants, at 90 days after transplantation, with the highest densities (12 345 and 13 888 plants ha^{-1}), the highest heights were obtained, with a record of 104.82 and 102.7 cm on average, and in the lowest densities (8 333 and 9 260 plants ha^{-1}), the height was lower (80.8 to 70.37 cm, respectively). On the contrary, González and Chamorro (2017) evaluated the effect of density on the growth and yield of the Reina Salvadoreña variety and determined that 4 444 plants ha^{-1} favored growth in basal diameter, crown diameter and a greater number of calyxes, not so for plant height and number of branches (Caro *et al*., 2012).

Basal diameter of the stem

In this variable, no significant differences were detected for factors a, b and their interaction (Table 1), they had an average value between 21.63 and 22.36 mm. In Nicaragua, González and Chamorro (2017) indicated that the lowest density of 4 444 plants ha^{-1} favored growth in basal diameter, while with a high density of 10 000 plants ha^{-1}, the basal diameter of the stem is smaller, a condition that is associated with less space for nutrients for its development. This statement is consistent when comparing high sowing densities with very low densities, however, in this study, the two densities could be considered as high. In Cuba, Terán and Soto (2004) did not observe a trend in six sowing densities, since the DBS intervals were similar, from 1.89 to 2.18 cm for 13 888 and 12 345 plants ha^{-1}, and in densities from 8 333 to 9 260 plants ha^{-1}, the DBS were from 1.83 to 2.15 cm, respectively.

Number of branches per plant

For this variable, no significant differences (p> 0.05) were found for factors a, b and their interaction; however, at 71 das the number of branches per plant in the four varieties and two sowing densities was very similar. At 103 das, the Estrella Costeña variety with a density of 13 888 plants ha^{-1} showed the highest record with 13 branches; at the lowest density for this date, an average of 10 branches per plant was obtained. For the 134 das, between 12 and 14 were obtained for all the treatments analyzed (Barrera *et al*., 2019).

In this case, the number of branches was not significant, but the height of the plant was, in this regard, it is known that the plant uses the available energy to increase the elongation of the stem and not to generate more branches (Salisbury, 1992). Hence, for this species, apical pruning is recommended to stimulate the formation of branches. Salinas and Bustillo (2012) identified a greater number of branches in low densities from 12 500 to 16 600 plants ha^{-1}, with 6 branches per plant. On the contrary, González and Chamorro (2017) detected that the low density favored the growth in basal diameter, crown diameter and greater number of calyxes, not so for the number of branches per plant.

Fresh weight of calyxes

The variable of fresh weight per plant showed no differences between the treatments for both factors and their interaction, but differences were obtained for the factor sowing density in fresh calyx yield per hectare (Table 1). The mean comparison test (Tukey, p> 0.05) with respect to density showed that the highest yield was obtained in the high density of 13 888 plants ha^{-1}, with an average of 4 947.6 kg ha^{-1}, while the low density of 8 264 plants ha^{-1} reached an average of 2 944.8 kg ha^{-1} in fresh yield of the calyxes (Table 2). For the factor varieties, no significant differences were detected, all varieties showed a similar behavior from 3 473.7 to 4 487.4 kg ha^{-1} (Table 2).

In the interaction between density∗variety, two groups were identified, in group a, which includes all varieties with the sowing density of 13 888 plants ha^{-1}, with an average yield between 4 073.8 to 5 871.5 kg ha^{-1}, the highest fresh yield was detected in the Estrella Costeña variety and the lowest in the regional control.

In group b, which included the four varieties in the low density of 8 264 plant ha^{-1}, the fresh yield ranged from 2 473.7 to 3 314.4 kg ha^{-1} (Figure 2). In the comparison of the highest yield (5 861 kg ha^{-1}, obtained in density 1 with the Estrella Costeña variety) with the lowest yield (2 874 kg ha^{-1}, obtained in density 2 and the regional control), there is a difference of 2 987 kg ha^{-1} of fresh weight of roselle calyxes in favor of the Estrella Costeña variety, which represents an increase of 51% in fresh weight yield.

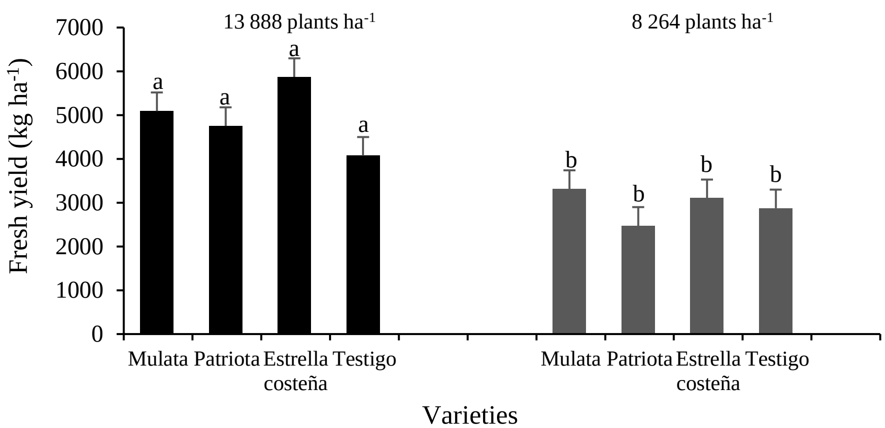

Figure 2. Fresh yield of calyxes of four roselle varieties established in two sowing densities. El Sifón, Gabriel Zamora, Michoacán.

For Terán and Soto (2004), the highest yields were obtained in the highest densities (13 888 and 12 345 plants ha^{-1}), where sowing densities behaved in correspondence with yields, and they reported 7.5 t ha^{-1} of fresh calyxes in the highest density and 4.5 t·ha^{-1} in the lowest density. Similarly, Salinas and Bustillo (2012) reported the highest yield in a high density of 50 000 plants ha^{-1} with sowing in September, and a yield of 8 835 kg ha^{-1}.

Dry calyx yield

In dry weight per plant, no differences were obtained between the treatments for both factors and their interaction; however, in the factor sowing density for yield of dry calyxes per hectare, there were significant differences ($p < 0.05$) (Table 1). In density 1 (13 888 plants ha^{-1}), it had the highest average yield of 573.27 kg ha^{-1}, while in density 2 (8 264 plants ha^{-1}), it was 351.17 kg ha^{-1}, with a difference of 222.1 kg ha^{-1} (Figure 3).

For their part, Terán and Soto (2004) indicate that with densities of 13 888 plants ha^{-1}, 87% more dry calyxes per hectare are obtained compared to a lower density of 8 333 plants ha^{-1}, which coincides with the results obtained in the present study. In the factor varieties, there were no significant differences ($p > 0.05$), nor in the interaction density∗variety (Table 1). However, numerically the best yield was obtained for the four varieties in the density of 13 888 plants ha^{-1}, where the highest yield was obtained by the Estrella Costeña variety, with a dry calyx yield of 679 kg ha^{-1}, followed by the Mulata and Patriota varieties with yields of 591 and 571 kg ha^{-1}, respectively. The lowest yields in dry weight for both correspond to the control variety (Estrella) with 452.1 and 347 kg ha^{-1} (Figure 3).

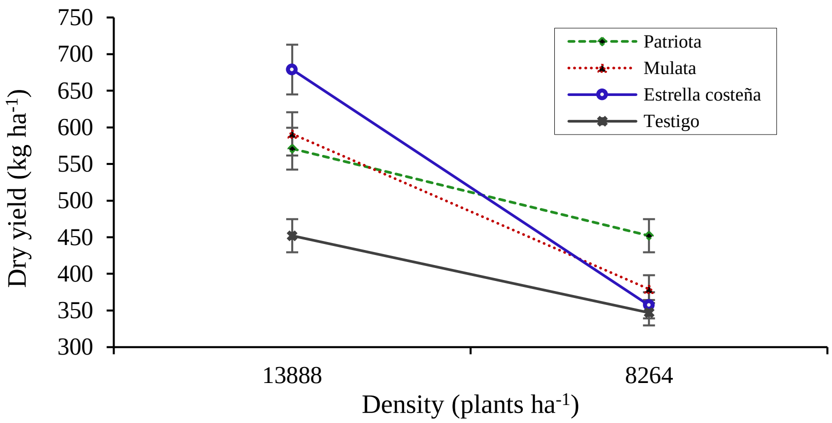

Figure 3. Interaction density*variety for dry yield of roselle calyxes. El Sifón, Gabriel Zamora, Michoacán.

When comparing the results of the yield obtained with the Estrella Costeña variety of this study, there is an average increase of 100 kg ha^{-1} in the yield per hectare, with respect to the yields reported in 2019 in Michoacán of 570 kg ha^{-1} (SIAP-SADER, 2022), with an average sale of $ 71.00, an extra profit of $7 100.00 pesos would be obtained. Similarly, when contrasting yields at the national level (430 kg ha^{-1}); however, what was reported in Morelos, 980 kg ha^{-1} of dry calyxes (SIAP-SADER, 2022), is not exceeded.

In this regard, González and Chamorro (2017), in Nicaragua, with a density of 10 000 plants ha^{-1}, reached the highest yield of 1 087.7 kg of DM ha^{-1}. In addition, they agree with Terán and Soto (2004), who mention that, in high densities, it allows obtaining 87% more dry calyxes per hectare compared to lower densities, where the yield was lower.

Correlation between variables

A positive and highly significant correlation was detected between the dry weight of the calyxes and fresh weight (r= 0.95, p< 0.0001); that is, the greater the fresh weight obtained from the calyxes, the greater the dry weight, which is directly correlated with the yield per hectare (r= 0.82, p< 0.0001; r= 0.86, p< 0.0001). The variable DBS was correlated (r= 0.63, p< 0.0001) with NB, which indicates that the greater the stem thickness, the greater the number of branches. The DBS is also correlated (r= 0.6, p< 0.0001) with DW, at a greater DBS, the dry weight of the calyxes increases, which is favorable to support a greater load on the plant.

Although sowing density is a factor that did not show a direct correlation with yield per hectare, it is a factor that affects other aspects such as plant development, growth in PHE and DBS in this case, since these variables are directly correlated with the calyx production of roselle plants, therefore, it was observed that, at high densities, the FW of the calyxes increases and in the same way the DW, demonstrating that it is convenient to establish crops with the varieties Patriota, Mulata, Estrella Costeña and control (Estrella) in densities of at least 13 888 plants ha^{-1} (density 1), since, as several authors point out, at a higher density, the number of calyxes increases and therefore the fresh and dry yield per hectare will be higher.

For this region that is within the dry tropics of the state of Michoacán, the results obtained with the four varieties (including the local control) exceed up to 65% those that have been commonly reported for the area and surrounding localities (SIAP-SADER, 2022). Therefore, the results obtained in the present study are of importance to improve the production of roselle in this region of the state of Michoacán, but other important aspects must also be considered, such as the integrated management of the crop and final commercialization of the product, or secondary products and derivatives of roselle.

Conclusions

The sowing density was decisive to increase the yield per hectare of calyxes in fresh and dry, with 13 888 plants ha^{-1}, the highest yield was obtained with 4 947.6 and 573.27 kg ha^{-1}. With this sowing density, the plants grew more than with the lower density. The four varieties evaluated showed a similar behavior for all variables, and numerically the Estrella Costeña variety showed the best fresh and dry yields (4 487.4 and 518.3 kg ha^{-1}) in both densities. But with the interaction in the density of 13 888 plants ha^{-1}, Estrella Costeña obtained 679 kg ha^{-1}, which exceeds the average reported for the region, and an increase of 17% in the average production is obtained, with an increase in profit of $7 029.00 pesos.

The variables fresh weight and dry weight were the ones that have the highest correlation with the yield ha^{-1}, with values higher than (r= 0.82), and a degree of confidence of 99.9%. The basal diameter of the stem was detected with less correlation with the number of branches and weight of dry calyxes per plant. If the Estrella Costeña variety is used with a density of 13 888 plants ha^{-1}, 15 to 20% increase in yield per hectare is obtained, in conditions of the tropics of the state of Michoacán.

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