__Original Research Article__

Agronomic evaluation of experimental lines of bell pepper under greenhouse conditions

ABSTRACT

Aims: The objective of this experiment was to evaluate agronomic performance of pepper lines under greenhouse conditions.
Study design: Was with the completely randomized model with 16 treatments (16 lines of bell pepper) and three repetitions each. The comparison of means was by Duncan≤.05.
Place and Duration of Study: Experimental greenhouse, Plant Breeding Department of the Universidad AutónomaAgraria Antonio Narro. between May 2022 to November 2022.
Methodology:sixteen lines of bell pepper were evaluated(Line 1, Line 2, Line 3, … Line 16), through the quantification and determination of agronomic variablesto determine its agronomic behavior.
Results: Significant statistical differences were identified in the variables,in fruit length and diameter, lines 1, 2, 6 and 16 were superior. In total soluble solids, lines 2 and 3 were superior. In mesocarp thickness, lines 1, 3, 9 and 10 stood out. In average fruit weight the best performing lines were line 16, line 2, line 7, line 6, line 13, line 1 with more than 170 g per fruit. In yield(kg planta^{-1} and yield calculated in t ha^{-1}), it was observed that lines 16, line 6, line 13 and line 14 produced more than 1.7 kilograms per plant, followed by lines 15, 1, 2, 4, 8 and 9 with 1.2-1.4 kilograms per plant on average. In plant height except for the lines 4, 2 and 1, the rest of the lines are statistically similar.A similar response was observed in number of fruits per plant, except for line 10. The correlation analysis expressed that the yield is determined by the number of fruits per plant (0.879), stem diameter (0.418), fruit diameter (0.268) and fruit length (0.255).
Conclusion: The agronomic behavior of the experimental pepper lines evaluated under greenhouse conditions was variable, therefore, the genetic diversity suggests the use of the outstanding attributes of each of the lines for the generation of new varieties or hybrids, or, where appropriate genetic recombination for the generation of new base populations for the derivation of new lines. he lines that stand out in most of the evaluated characters were line 1, line 2, Line 5, line 6, line 7, line 13, line 14 and line 16.

Keywords: Capsicum annuum, yield,genetic, genotypes, plant breeding.

1. INTRODUCTION

In the world, the obtaining and availability of quality seeds is one of the most crucial factors for agricultural productivity and global food security, Mexico is no exception. However, there have been various challenges and problems faced by the country in this regard, which negatively impacts agriculture and the rural sector. The availability of seeds of high genetic and physiological quality is essential for the success of crops; however, in Mexico, the lack of access to improved and, above all, certified varieties limits the productivity and competitiveness of crops. small and medium farmers [1].On the other hand, the lack of a clear and coordinated policy regarding obtaining, producing and distributing certified seeds makes access to high-quality seeds even more difficult [2].Another critical aspect identified is the low investment in research and development of new national varieties of various crops, which has led to an excessive dependence on imported seeds and has slowed the development of local varieties adapted to the specific conditions of Mexico and its productive regions [3].

The bell pepper (*Capsicum annuum* L.) is one of the most important horticultural crops in Mexico, both for domestic consumption and for export. Traditional genetic improvement has been fundamental in obtaining varieties with desirable characteristics such as size, color, flavor and resistance to diseases or abiotic stress.Mexico has a rich tradition in the genetic improvement of chili peppers, which has contributed significantly to its development and diversification [4].However, chili improvement has focused on the selection of local varieties with outstanding attributes, such as ancho chili, poblano chili, and güero chili.This approach has allowed farmers to have seeds adapted to local conditions and with high acceptance in national and international markets, in addition, the importance of the genetic diversity present in pepper varieties in Mexico is highlighted, developing new varieties through selective crossings to generate base populations [5].

This genetic diversity has allowed the obtaining of varieties with different colors, shapes and levels of heat. Despite the achievements obtained, it is necessary to continue strengthening the traditional genetic improvement of peppers, promoting the conservation of genetic diversity and encouraging the participation of farmers in the seed selection and conservation process [6]. The objective of this research was to evaluate experimental lines of bell pepper agronomically, in order to select those lines that show outstanding attributes that can be used for the generation of new varieties or hybrids.

2. MATERIAL AND METHODS

2.1. Location

The research was carried out in a medium technology greenhouse of the Plant Breeding Department of the Universidad AutónomaAgraria Antonio Narro (UAAAN), in Saltillo, Coahuila, located at 25° 21´ 24´´ LN and 101° 02´ 05´´ LO, at 1762 meters above sea level.

2.2. Genetic Material and Seedling Production

The genetic material used belongs to the Seed Technology Training and Development Center of the Plant Breeding Department of the Antonio Narro Autonomous Agrarian University. The desired characteristics such as color, shape, size, appearance and appearance were taken into account for selection and testing. weight of the results obtained in a previous evaluation and selection cycle. The experimental lines were identified as: line 1, line 2, line 3, line 4, line 5, line 6, line 7, line 8, line 9, line 10, line 11, line 12, line 13, line 14, line 15 and line 16.The seeds were sown on February 21, 2021 in 200cavity polystyrene trays, the germination substrate was peat moss and perlite, in a 70:30 % ratio, respectively.

2.3. Field Establishment and Crop Management

The experiment was carried out in a low-tech saw-type greenhouse, with a completely randomized experimental design, with sixteen treatments and three repetitions each. The distance between plants was 15 cm and between rows was 1.8 m, thus generating an approximate population density of 33,300 plants per hectare.

The transplant was carried out 68 days after sowing the seeds and was carried out in coconut fiber in a pen, with a distance of 15 cm between plants, each plant led to a double stem. The supply of water and nutrients was by localized irrigation, with approximately 10 % drainage. The nutrient solution used for crop nutrition was modified Steiner type [7] as shown in Table 1 (50 % after transplant, 75 % at the beginning of flowering and 100 % at fruiting and filling), maintaining a pH range of 5.9-6.1 and an electrical conductivity of 1.5 to 2.7 dS/m in the nutrient solution according to its concentration. There were genotypes representing four treatments, each with four repetitions, so each repetition consisted of six plants, one at each end as a border and four measurable and quantifiable useful plants. For the prevention and control of pests (whitefly, thrips, paratrioza), weekly applications were made of Spirotetramat at 15.3%, Spiromesifen at 23.1 %, Imidacloprid 17 % + betacylfutrin 12 % at a rate of 1 ml L^{-1}.

Table 1. Nutrient solution (SN) and the percentages used in the stages of bell pepper cultivation under greenhouse conditions.

	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	Cl^-	HCO_3^- y CO_3^{2-}	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	Na^+
% SN	**Miliequivalentes L^{-1}**									
100	12	2	7	3.26	1	2	7	4.5	9	3

75	9	1.5	5.25	3.26	1	1.5	5.25	3.4	6.75	3
50	6	1	3.5	3.26	1	1	3.7	2.5	4.5	3

The irrigation system was established by localized irrigation with pegs. Once the peppers were transplanted, the first week they were irrigated with water without fertilizer. Subsequently, the irrigations were carried out with the corresponding nutrient solution, a 2500-liter tank was prepared where the nutrient solution was stored, likewise, an irrigation pump was used that was connected to a digital timer in order to have automated irrigation on a schedule basis. According to the growth of the pepper plants, they were staked with double stems each, each stem was aligned vertically using black agricultural raffia with a density of $1g.m^{-2}$, where they were supported by the wires of the stake. of the greenhouse, this tutoring was carried out every week to keep the stems always upright in a vertical line and not run the risk of breaking the stems.Pruning was carried out during the establishment of the crop, performing training pruning. At 40 days after transplanting, the stems with less vigor were removed and only two main stems per plant were left for all the lines evaluated. For this activity, scissors were used. for pruning, washed and disinfected with 2% chlorine.

Once the stage was completed, the harvest was carried out (107 days after transplanting). The pepper fruits were cut when they showed an external coloration greater than 50%, a red color characteristic of each line. All the fruits of each line evaluated were collected, marked and separated in bags and boxes to fully identify them. Likewise, two harvests were carried out during the crop cycle, the first was 107 days after the transplant on August 14, 2022 and later on September 3, the second harvest was 127 days after the transplant.

2.4. Evaluatión of Agronomic Variables of the Crop

The stem diameter (SD) was quantified in mm, and was three centimeters from the base of the substrate, with a STEREN® digital vernier (HER-411), and plant height (PH) through the use of a PRETUL® (PRO-5MEB) flexometer graduated in centimeters. Fruit length: To obtain the fruit length variable, each harvested fruit was measured with a STEREN® digital vernier (HER-411). Equatorial diameter of the fruit: This variable was quantified with a STEREN® digital vernier (HER-411), taking the measurement of each harvested fruit in its equatorial diameter, and according to its respective lines. Mesocarp thickness: To obtain this variable, the fruits were cut on their equatorial side and with the help of a STEREN® digital vernier (HER-411), the thickness measurement was taken. For the yield in kilograms per plant (kg $plant^{-1}$), the fruits of each plant and each harvest were weighed on a Torrey® scale model LPCR40, the variable number of fruits per plant was obtained by counting and adding the harvested fruits. of each plant and each harvest, while the average weight of the fruit resulted from dividing the total weight of the fruits of each plant by the number of fruits of the same plant. The yield calculated in tons per hectare ($t\ ha^{-1}$) was obtained by multiplying the yield of each plant by the total number of plants in a hectare according to the spatial distribution of the experiment.To determine total soluble solids in the fruit (° brix in percentage), small pieces of fruit were cut with a knife, which were pressed to obtain a few drops of juice that were placed in the SOONDA® digital refractometer (TD6010, China).

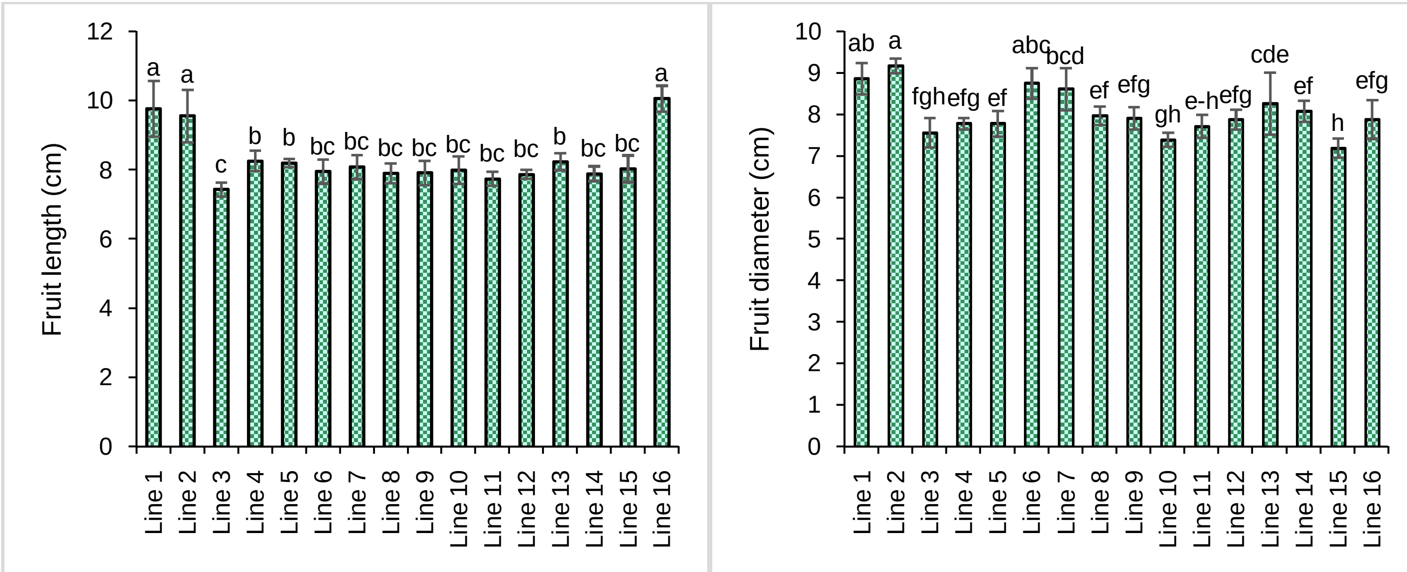
2.5 Experimental Design

The treatment design and the statistical model were completely randomized, with 16 treatments and three repetitions each, each repetition with four measurable and quantifiable useful plants. With the data obtained, an analysis of variance (ANOVA) was performed, and for the detection of statistical differences between genotypes, the Duncan mean comparison test ($p \leq 0.05$) was used using the statistical package InfoStat/L (InfoStat® version 2020).A correlation analysis was also carried out with the Spearman methodology in the statistical package InfoStat/L (InfoStat® version 2020).

3. RESULTS AND DISCUSSION

3.1. Agronomic Performance

The analysis of variance and comparison of means (Duncan *p*≤0.05), of the fruit length variable (Figure 1A), indicates significant differences between the lines evaluated, where line 1, line 2 and line 16 are superior to the rest in more than 20%. While, in the fruit diameter variable (Figure 1B), it is observed that lines 1, 2 and 6 showed a better statistical response by surpassing the rest of the lines, these were followed by line l7 and 13, while that the lines with the smallest fruit diameter were lines 15 and 10, the rest showed an intermediate result.



(A) **(B)**

Figure 1. Comparison of means and standard deviation of fruit length (A) andfruit diameter (B),evaluated in 16lines of bell pepper under greenhouse.

Figure 2A shows the results of the analysis of variance and the comparison of means (Duncan p≤0.05) of the variable number of fruits per plant, where it is observed that, with the exception of line 10, the rest of the experimental lines showed a very similar statistical behavior, therefore, there are no statistical differences between the lines, although the lines that managed to produce 10 fruits per plant on average were line five, six, fourteen and sixteen.In the average fruit weight variable (Figure 2B), significant statistical differences were observed in the response of the lines according to Duncan's test of means p≤0.05, where it is clearly seen that the lines with the best performance were line 16, line 2, line 7, line 6, line 13, line 1 with more than 170 g per fruit, followed by lines 8, 9, 12, 14 and 15 with more than 150 g, the rest of the lines were less than the aforementioned.In the yield variable in kilograms per plant (Figure 2C), significant differences were found according to Duncan's test of means p≤0.05, where it is observed that lines 16, line 6, line 13 and line 14 produced more of 1.7 kilograms per plant, followed by lines 15, 1, 2, 4, 8 and 9 with 1.2-1.4 kilograms per plant on average, the rest of the lines showed a lower response than those mentioned above, and it was line 10 and 3 the worst performing. In the yield calculated in tons per hectare (Figure 2D), the response of the lines was the same, considering a planting density of 33,300 plants per hectare with double stems each.

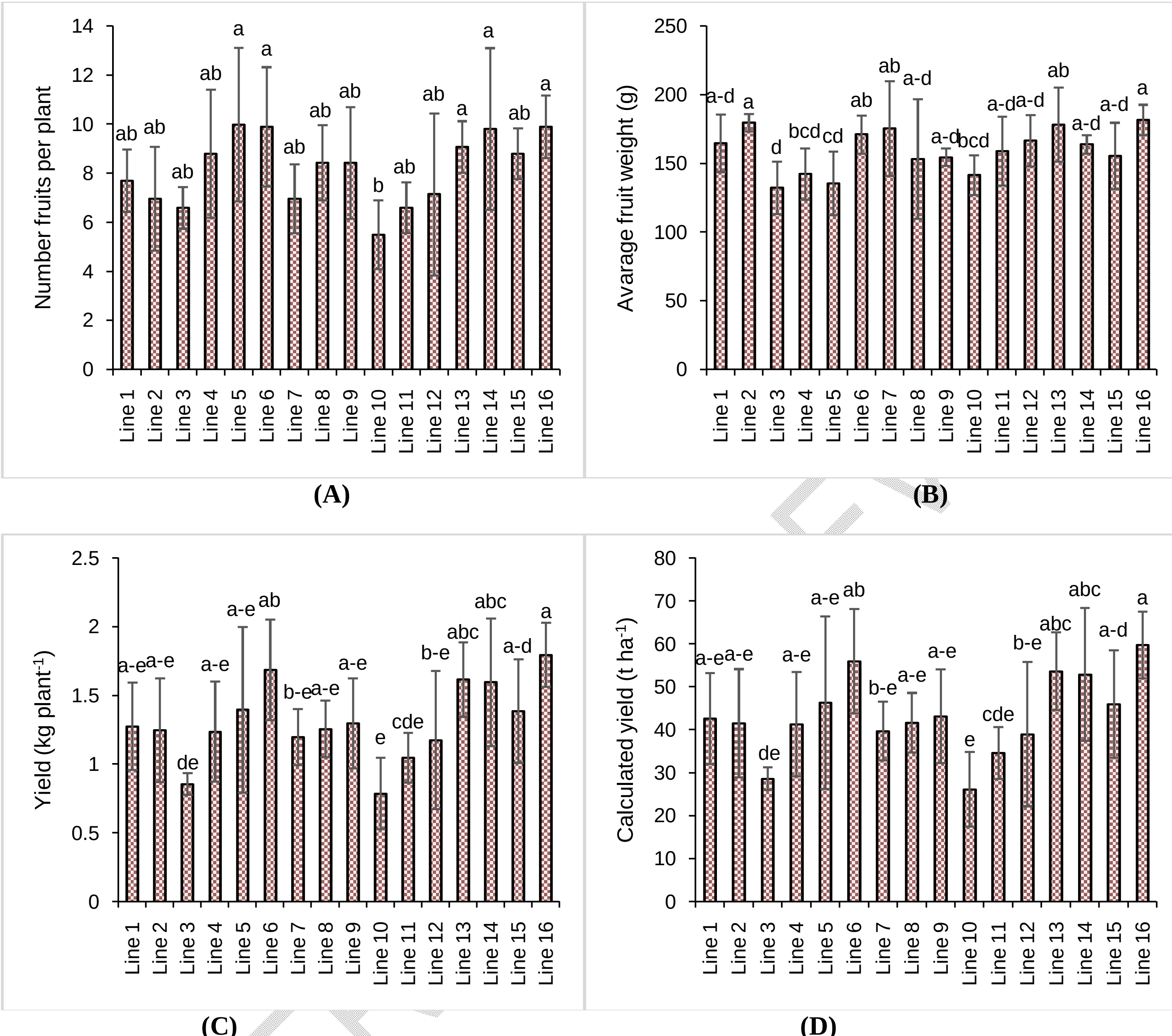
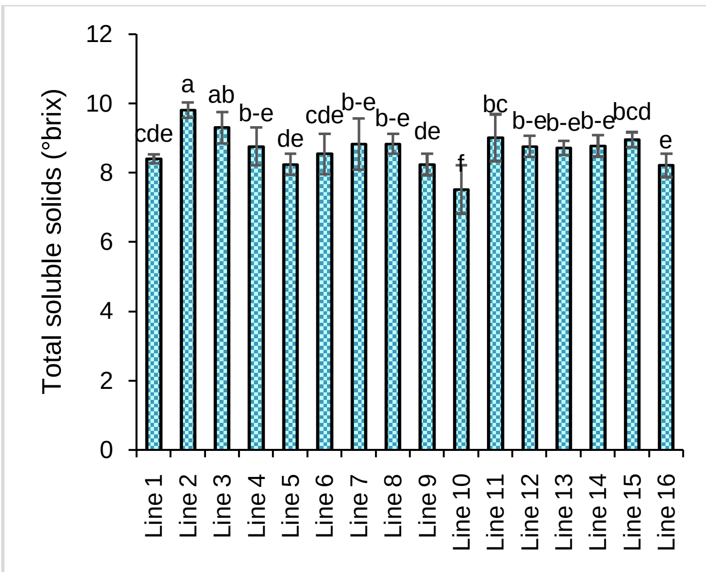
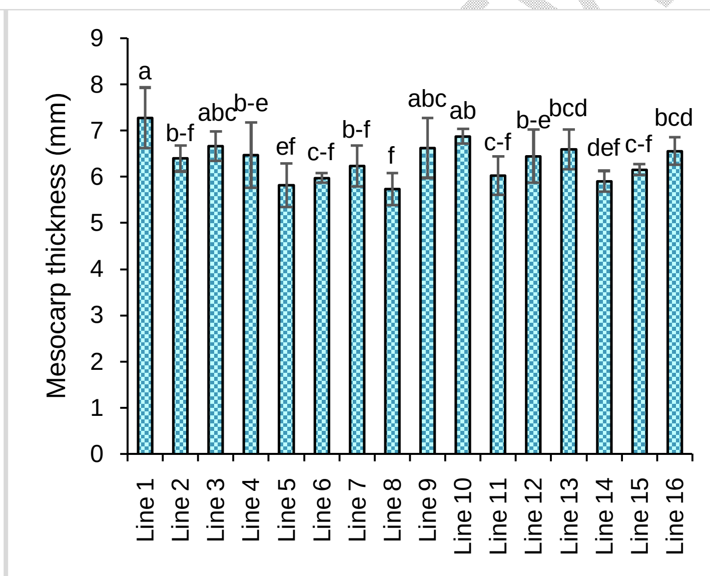


Figure 2. Comparison of means and standard deviation of number fruits per plant (A),average fruit weight (B), yield in kilograms per plant (C) and yield calculated in tons per hectare (D),evaluated in 16lines of bell pepper under greenhouse.

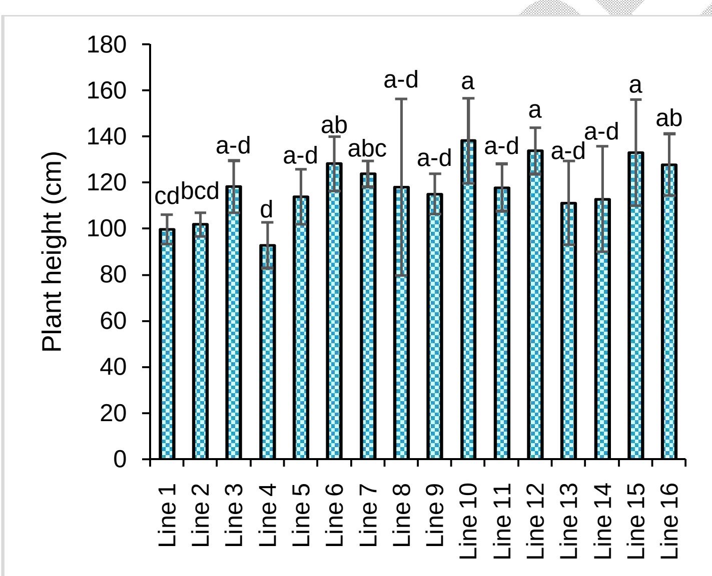
In Figure 3A, for the variable total soluble solids (°brix), significant statistical differences were found between the lines according to Duncan's test of means p≤0.05, with lines 2 and 3 standing out with more than 9 degrees. brix, while the lines with the lowest values were lines 10 and 16, the rest of the lines showed intermediate values between 8.2 and 8.5 degrees' brix.Figure 3B shows the variable thickness of the mesocarp where a significant statistical difference was found between the response of the lines. It is observed that line 1 stood out with 7.1 mm of mesocarp thickness, although it is statistically equal to lines 3. line 9 and line 10, while the one with the smallest mesocarp thickness were lines 8, 5, 6, 11 and 14, the rest of the lines obtained intermediate values.Figure 3C shows the response of the plant height variable, where significant differences are observed, where with the exception of lines 4, line 2 and line 1, the rest of the lines are statistically similar to each other according to the test. Duncan means p≤0.05, although lines 10 and 15 exceed line 4 by 30%. In the stem diameter variable, no significant statistical differences were found (Figure 3D), therefore, the response of the lines was similar.



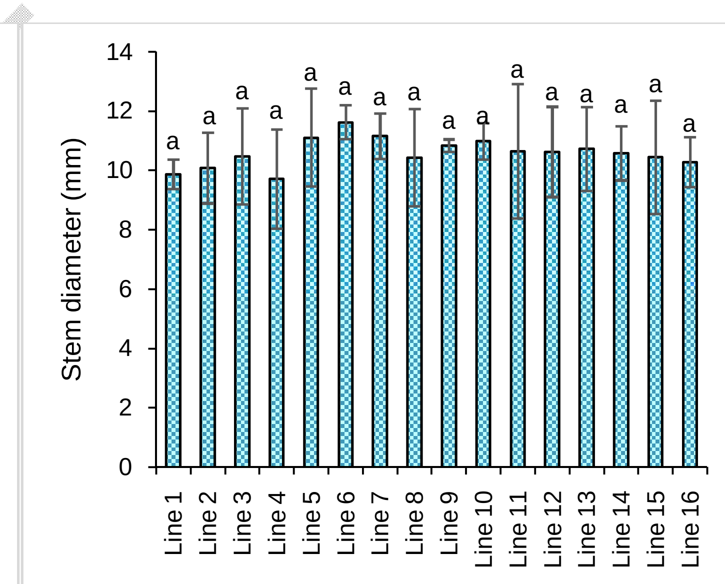
(A)



(B)



(C)



(D)

Figure 3. Comparison of means and standard deviation of total soluble solids (A),mesocarp thickness (B), plant height (C) and stem diameter (D),evaluated in 16lines of bell pepper under greenhouse.

3.2. Pearson Correlation Coefficient

In Table 2, you can see the Pearson correlation coefficient, among the response variables, the yield is determined by the number of fruits per plant (0.879), stem diameter (0.418), fruit diameter (0.268) and fruit length (0.255). The average fruit weight is influenced by fruit diameter (0.358), plant height (0.304) and yield (0.454). The number of fruits per plant is determined by the thickness of the stem (0.36), the thickness of the mesocarp is mostly determined by the length of the fruit (0.335) and finally the stem diameter is influenced by the height of the plant (0.445).

Table 2. Pearson correlation coefficient of variables evaluated in bell pepper chili grown under greenhouse conditions.

	FL	FD	TSS	MG	PH	SD	NFP	REND	AFW
FL	1								
FD	0.411**	1							
TSS	-0.091	0.148	1						
MG	0.335*	0.082	-0.213	1					
PH	-0.247	-0.219	-0.209	-0.138	1				
SD	-0.133	0.111	-0.245	-0.104	0.445**	1			
NFP	0.151	0.128	-0.128	-0.209	-0.205	0.36**	1		
REND	0.255*	0.268*	-0.098	-0.16	-0.026	0.418**	0.879**	1	
AFW	0.223	0.358**	0.075	-0.026	0.304*	0.197	-0.01	0.454**	1

*= significant p≤0.05, **= highly significant p≤0.01. FL= Fruit length, FD= fruit diameter, TSS= total soluble solids (°Brix), MG= mesocarp thickness, PH= plant height, SD= stem diameter, NFP= number of fruits per plant, REND= yield and AFW= average fruit weight.

4. Discussion

4.1. Agronomic performance

The variable length of the pepper fruit is one of the most relevant factors, since it provides appearance and presentation to the fruits, which influences how the quality can be perceived and, consequently the nutritional content [8]. Improving the length of bell pepper fruits is one of the important objectives in genetic improvement programs, since this can improve the quality of final production, which may indicate that it is possible to select bell pepper lines with longer fruits by selective and directed crossings [9], in this research it was found that lines 1, 2 and 16 are superior for this character with an average of 9.8 cm, which are very similar to those reported in the Janette F1 variety, which presented an average fruit length of 10.9 cm [10], which indicates great potential of said line for the attribute in question and presumably continue with the selection process.The diameter of the bell pepper fruits is also one of the key characteristics to evaluate, this has a direct impact on the commercialization and acceptance of the product in the market, because those with a larger diameter are usually preferred by consumers, given that they offer a higher pulp content and sometimes a higher content of vitamins and minerals [11]. The results obtained in the investigation show that Line 2 has 9.18 cm in diameter, this being slightly smaller than the 9.28 cm reported [12].

The number of fruits per plant is one of the key factors of crop yield; an optimal number of fruits per plant can contribute to an adequate balance of nutrients within the plant and balance the number of fruits [13], the number of fruits is influenced by both genetic and environmental factors, therefore, through genetic improvement programs, the aim is to increase the yield of plants by increasing the number of fruits and their quality [14], in this research it is observed that lines 5, 6, 14 and 16 produced 10 fruits per plant on average, which are much higher than the 7.4 fruits per plant that have been reported in the Cannon variety. blocky type [15], this provides a greater opportunity to continue genetically improving these lines or, where appropriate, the recombination of characters with other lines for the generation of hybrids with high productive potential and at the same time the recombination of characters to create variable populations.

The variable average fruit weight is related to the quality of the fruit, because fruits with a greater weight are perceived as having greater freshness and greater flavor, this generates a high commercial value, because larger fruits promote greater weight accumulation and if There is a considerable number, they could contribute to the improvement of yield [16], there is a great genetic variability between the lines under evaluation, which indicates that it is possible to select varieties with heavier fruits and that are adaptable to changing environmental conditions [17. The pepper lines that were superior were lines 2, 6, 7, 13 and 16 with an average weight of 170 g, which indicates great genetic potential of this attribute, since compared to other research where up to 206 grams of medium weight in hybrids such as Godzilla [5], being slightly superior to the mentioned lines considering that it is a hybrid, therefore, high potential is inferred to continue genetically improving this attribute.

Yield per plant is a key indicator of productive efficiency, which reflects the capacity of plants to produce fruits under specific conditions, with this the efficiency in the use of resources can be increased, seen from all angles and at the same time. time reduce production costs [18], the yield calculated in tons per hectare is a parameter that helps to evaluate the profitability and sustainability of crops, because it represents the total capacity of the plants to produce fruits harvested and marketed in a given area [19]. To obtain the best yields, genetic improvement programs must be taken into account and the environmental adaptations with which they will be worked must be observed, in order to increase the productivity and profitability of crops [20], in the present investigation in the yield variables in kilograms per plant and the yield calculated in tons per hectare, it is observed that the lines that stood out were 6, 16, 13 and 14, however line 16 produced up to 1.8 kilograms per plant on average, while in the case of the calculated yield variable the average of line 16 was 59.8 tons per hectare, prioritizing the context that only two harvests were carried out concentrated in the crop, in the case of yield per plant have reported up to 1.92 kilograms per plant and up to 76.35 tons per hectare in the Vikingo variety with Spanish-type tutoring [21].

The study also shows that there is a statistically similar response in the stem diameter of all the lines, this is very important because a greater increase in the stem diameter in the plants generally provides greater stability, especially under conditions of wind or intense rain, which can prevent damage and loss of fruits [22], this variable may be related to the efficient transport of water and nutrients that determine the yield, size, flavor and content nutritional of fruits [23], the values obtained in stem thickness are slightly lower than the 13.8 mm achieved by the California Wonder variety [4].

The agronomic performance of a crop depends on the variety that is planted, however, it also depends on the environmental conditions during its growth and development, the management of the crop, as well as the availability of nutrients and moisture in the culture medium [24].To the above is added an adequate supply of water, in order to achieve performance goals, of course without neglecting the ionic balance of the nutrients that accompany it [25].Improving the agronomic performance of any crop is largely based on the existence of existing genetic variability, and the magnitude of beneficial genetic variability available [26]. And the characters: plant height, fruit length, fruit width and number of fruits per plant turn out to be of high heritable capacity, so the selection of new materials should be made based on these characters [27, 28].Also, average fruit weight, number of fruits per plant, number of seeds and yield, these traits could be improved by recurrent selection effectively [29].The environment and growing conditions also determine the agronomic performance, especially the yield of the bell pepper crop [30].

4. CONCLUSION

The agronomic response of the experimental pepper lines evaluated under greenhouse conditions was variable, therefore, the genetic diversity suggests the use of the outstanding attributes of each of the lines for the generation of new varieties or hybrids, or, where appropriate. genetic recombination for the generation of new base populations.

The lines that stand out in most of the evaluated characters were line 1, line 2, Line 5, line 6, line 7, line 13, line 14 and line 16, which suggests the continuation of the genetic improvement program, in order to refine and find the outstanding lines in the characters that contribute the most to performance, which will eventually allow the generation of new varieties and/or hybrids.

The evaluation analysis indicates that the yield of pepper is determined by the number of fruits per plant, stem diameter, fruit diameter and fruit length, the number of fruits per plant is determined by the thickness of the stem, the thickness of the mesocarp influenced by fruit length and finally the stem diameter correlated with the height of the plant.

DISCLAIMER (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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