Agronomic response of experimental hybrids of poblano pepper under shade cloth in Coahuila, Mexico

Camposeco-Montejo, N.[1]; Marín-Cortez, Ma. del P.[2*]; Flores-Naveda, A.[1]; García-López, J. I.[1]; Álvarez-Vázquez, P.[3]; Gordillo-Melgoza, F. A.[1]

[1] Universidad Autónoma Agraria Antonio Narro, Departamento de Fitomejoramiento. Calzada Antonio Narro 1923, Col. Buenavista, C.P. 25315, Saltillo, Coahuila, México.
[2] Universidad Autónoma Agraria Antonio Narro, Departamento de Horticultura Calzada Antonio Narro 1923, Col. Buenavista, C.P. 25315, Saltillo, Coahuila, México.
[3] Universidad Autónoma Agraria Antonio Narro, Departamento de Recursos Naturales Renovables. Calzada Antonio Narro 1923, Col. Buenavista, C.P. 25315, Saltillo, Coahuila, México.
* Correspondence: pili.saku21@gmail.com

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ABSTRACT

Objective: To evaluate the agronomic response of sixteen experimental hybrids of poblano pepper under shade cloth in Coahuila, Mexico.

Design/methodology/approach: The design of treatments and the statistical model was completely randomized with 16 treatments and four repetitions each, analyzed with an ANVA at $p \leq 0.05$ and Tukey's means test $p \leq 0.05$.

Results: In yield (kg plant^{-1}), the hybrids AN-103, AN-203, AN-204, AN-302, AN-401, AN-402 and AN-403 were superior; in average weight of the fruit the hybrids AN-203, AN-302, AN-402 and AN-304 stood out; the fruit length was greater in the hybrids AN-302, AN-304, AN-401, AN-402, AN-403, AN-404, AN-204 and AN-103; the number of fruits per plant was very similar in most of the hybrids; the hybrid AN-302 produced the widest fruits in its basal part near the peduncle, and it also stood out in the width at the center part of the fruit. The number of fruits per plant, average fruit weight and average fruit width are the attributes that contribute the most to yield, whose Pearson correlation is 0.74, 0.55 and 0.44.

Findings/Conclusions: The hybrids that showed a favorable agronomic response in most of the attributes evaluated were AN-401, AN-402, AN-203, AN-302. The agronomic response of the experimental hybrids was variable in most of the traits evaluated; therefore, the genetic potential of each of the hybrids is different and is reflected in their phenotypic response under the specific conditions of the environment in which they developed.

Keywords: *Capsicum annuum*, phenotype, attribute, quality, performance.

INTRODUCTION

Chili pepper (*Capsicum annuum* L.) is one of the native species from Mexico, and Olvera *et al.* (1998) point out that there are records of its cultivation since the year 7,000

to 2,555 BC, primarily in the states of Puebla and Tamaulipas. The production of this crop is a fundamental part of the economy in the local, regional and national scope. In Mexico, in the agricultural year 2022, the planted surface of green chili pepper was 158,000 hectares, of which 16,700 hectares correspond to poblano type chili pepper (16,091 were grown in the open, 553 under greenhouse, and 46 under shade cloth), and average a yield of 25.03 tons per hectare. When it comes to dehydrated ancho chili pepper, the planted surface exceeds 15,000 hectares, and it is precisely its forms of trade that confer it versatility in the chili pepper market, whether in green fruit as "poblano chili pepper" or dehydrated as "ancho chili pepper". The states that lead the production of poblano pepper are Zacatecas, Guanajuato and Sinaloa, and for ancho chili pepper they are Zacatecas and San Luis Potosí (SIAP, 2022). However, the use of criollo seed is still frequent, particularly with small-scale producers, which sometimes generates low yields due to inadequate selection and obtainment of seed (Marín *et al.*, 2013), and the problem represented by diseases, particularly in the soil (Pérez *et al.*, 2016; Macías *et al.*, 2009). There is also a lack of economic resources, high cost of inputs, and scarcity of water resources (Galindo *et al.*, 2002). In addition, changes in the agrometeorological conditions are favoring adverse situations, which induce problems in production, generating economic loss, primarily for small-scale farmers (Joukhadar and Walker, 2020). It is precisely the lack of adaptability of the varieties to such environmental changes that impact their productivity most (Kumari *et al.*, 2019); therefore, it is important to conserve and to improve the broad diversity and genetic variability of this crop (Pérez *et al.*, 2016), in order to foster its adaptation to adverse environmental and increasingly less predictable conditions (Aguilar *et al.*, 2010).

One of the alternatives to face the problems cited before is plant breeding, which has favored the generation of new varieties with higher yield, of better commercial and nutritional quality, greater resistance to adverse abiotic and biotic factors, and greater adaptation to different environmental conditions (Torres, 2018; Aguirre and Muñoz, 2015). Hybridation is the technique that allows the creation of improved hybrid varieties, with greater genetic potential in every sense (Acquaah, 2012), and which at the same time contribute to the sustainability of the agricultural and livestock systems (Camarena *et al.*, 2014). On the other hand, protected agriculture, which is defined as the type of agriculture where crops are protected under any type of cover with the aim of controlling radiation, temperature and relative moisture (SADER, 2020), has increased in Mexico at a rate of 14% annually since 2015 to date. Of the 51,852 protected hectares, 20,800 correspond to shade cloth, where tomatoes, chili peppers and cucumbers are primarily cultivated (SIAP, 2022); hence, the importance of understanding the agronomic behavior of new hybrids or varieties under specific conditions, mainly under protected environments (Maboko and Du Plooy, 2018).

The diversity of chili peppers found in the country (Mercer and Perales, 2010) represents an area of opportunity for the improvement of their agronomic traits through geneticist methods (Toledo *et al.*, 2016). In addition, the growth rate in protected agriculture sets the standards, and therefore, the objective of this study was to assess the agronomic behavior of experimental hybrids of poblano pepper under conditions of shade cloth in Coahuila.

MATERIALS AND METHODS

Location of the experiment

The study was conducted under shade cloth located in the "El Bajío" experimental field of Universidad Autónoma Agraria Antonio Narro (UAAAN), Saltillo, Coahuila, Mexico, located on 25° 21' 24" LN and 101° 02' 05" LW, at 1762 masl. The mean annual precipitation is 400 mm and the mean annual temperature 18 to 22 °C. The field work was carried out in the period of May to December in 2021.

Plant material

Sixteen experimental hybrids of poblano pepper were used, developed in the Centro de Capacitación de Desarrollo en Tecnología de Semillas del Departamento de Fitomejoramiento (Table 1), of Universidad Autónoma Agraria Antonio Narro.

Seedbed stage

Seeds from the hybrids were planted in polysterene trays of 200 cavities, and the germination substrate consisted of peat moss and perlite in a proportion of 70:30%, respectively. A commercial formula of 20-30-10 added with microelements was used for seedling nutrition, 0.5 g L^{-1} five days after the emergence, 0.75 and 1 g L^{-1} at 15 and 30 days after the corresponding emergence until before the transplant.

Establishment in the field and crop management

The transplant was conducted 64 days after having sown the seeds, and it was carried out in a loam soil with the characteristics described in Table 2. It was during the 2022 fall-winter cycle, the cultivation beds were 25 cm high, the distance between the beds was 1.80 m, and the distance between plants was 30 cm in a single row.

Irrigation was carried out through a dripping irrigation system, which consists in an irrigation strip with caliber 6000 Aquatrax®, with droppers at 20 cm and expenditure of 0.75 liters per hour; the soil was supplied with daily irrigation until reaching the field capacity, the irrigation water quality is described in Table 3. The total nutrition applied via fertirrigation during the cultivation cycle was 170-80-270 of N-P_2O_5-K_2O.

Table 1. Plant material of the study evaluated under conditions of shade cloth in Coahuila, Mexico.

Identification code	Origin	Identification code	Origin
AN-102	Coahuila	AN-301	Coahuila
AN-103	Coahuila	AN-302	Coahuila
AN-104	Coahuila	AN-304	Coahuila
AN-101	Coahuila	AN-303	Coahuila
AN-201	Coahuila	AN-401	Coahuila
AN-203	Coahuila	AN-402	Coahuila
AN-204	Coahuila	AN-403	Coahuila
AN-202	Coahuila	AN-404	Coahuila

Table 2. Physicochemical characteristics of the analysis of soil fertility, where experimental hybrids of poblano pepper were established under shade cloth.

Physical-chemical characteristics of the soil							
Textural class	**Apparent density ($g.cm^{-3}$)**	**pH (1:2 water) alkaline**	**Total carbonates (%)**	**Salinity (CE extract 1:2 water) Ds/m**	**SP (%)**	**FC (%)**	**PWP (%)**
Loam	1.25	8.61	8.25	1.1	40	21.3	12.7
Macronutrients in parts per million (ppm)							
N - NO_3^-	**P-Olsen**	**S**	**Cl**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**
39.7	65	55.9	ND	658	3995	321	106
Micronutrients in parts per million (ppm)							
Fe^{3+}	**Mn^{2+}**	**B^{3+}**	**Zn^{2+}**	**Cu^+**	**Mo^{2+}**		
2.07	3.11	1.31	4.95	0.51	ND		

SP=Saturation point, FC=Field capacity, PWP=Permanent wilting point, pH=Hydrogen potential, ND=Not determined.

Table 3. Characteristics of irrigation water that was used for water and nutrient supply to the crop.

Macronutrients in Milliequivalents L^{-1}								
NO_3^-	**$H_2PO_4^-$**	**SO_4^{2-}**	**Cl^-**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**HCO^{3-}**
0.41	ND	1.61	2.2	0.1	5.57	2.42	3.22	7.56
Micronutrients in parts per million (ppm)								
Fe^{3+}	**Mn^{2+}**	**B^{3+}**	**Zn^{2+}**	**Cu^+**	**Mo^{2+}**	**pH**	**CE (Ds/m)**	**RAS**
0.0118	0.0047	0.4	0.0891	0.0122	ND	7.5	1.15	1.61

pH=Hydrogen potential, EC=Electric conductivity, SAR=Sodium absorption rate.

The poblano pepper plants were not pruned, so they required support during their growth to avoid breaking of the branches from the weight of fruits; the tutor used to keep the plants upright was the Spanish or "strapped" type, the distance between logs was five meters, and four tutoring actions were carried out throughout the cultivation cycle.

For pest control (white fly, trips, paratriosis), weekly applications of Spirotetramat at 15.3%, Spiromesifen at 23.1% and Imidacloprid 17%+betacylfutrin 12% at a rate of 1 ml L^{-1} were made. The weeds were eliminated with mattock and manually every 15 days.

Quantification of the response variables evaluated

Only one harvest was conducted in the cultivation cycle, and it was 90 days after the transplant, which took place on August 20, 2022, and it was conducted manually at the time when the fruit reached its commercial maturity. The yield (g $plant^{-1}$) resulted from adding the weight of the fruits from each plant, which were weighed in a digital precision scale Sartorius (TS 1352Q37, Gottingen, Germany). After weighing the fruits, the number of fruits from each plant (NFP) was counted, while the average fruit weight (AFW) was calculated by dividing the total weight of fruits by the total number of fruits from each plant; meanwhile, the base width, medium width, and fruit length (BW, MW and FL) were estimated taking eight fruits randomly per repetition, and a Truper® brand digital Vernier (CALDI-6MP, Atlacomulco, Mexico) was used. The plant height was

determined with a Truper® brand flexometer calibrated in centimeters (PRO-5MEC Atlacomulco, Mexico), while the stem thickness was determined at the time of the harvest in four plants per repetition with a Truper® brand digital Vernier (CALDI-6MP, Atlacomulco, Mexico), the calyx depth, length of the peduncle, and thickness of the mesocarp (in mid-cut of the fruit), were determined in the same fruits that were used to quantify BW, MW and FL, with a Truper® brand digital Vernier (CALDI-6MP, Atlacomulco, Mexico).

Description of treatments and statistical analyses

Sixteen experimental hybrids of poblano pepper were assessed under a completely randomized experimental arrangement and since all the treatments were under shade cloth in an area of 450 m^2, whose soil analysis was described in Table 2, it allowed minimizing the environmental variability. Meanwhile, the statistical analysis was carried out with the INFOSTAT 2019 software; first the normality test was conducted, so it was not necessary to perform data transformation, and their analysis was carried out with the completely random linear statistical model with 16 treatments and four repetitions each (ANVA $p \leq 0.05$), each repetition with four measurable and quantifiable useful plants. For the means comparison, Tukey's test was conducted (Tukey $p \leq 0.05$). The correlation analysis was carried out with Pearson's methodology. The data obtained were analyzed with the Infostat® version 2019 statistical software.

RESULTS AND DISCUSSION

According to Tukey's means test $p \leq 0.05$, in the variable of yield in kilograms per plant, it was observed that the hybrids AN-103, AN-203, AN-204, AN-302, AN-401, AN-402 and AN-403 are statistical equal, although superior to the rest of the tested hybrids; however, among them the AN-402 stands out; while the hybrids with lowest yield were AN-303, AN-104 and AN-301, the rest of the hybrids kept a range of yield between 0.35 and 0.45 kg plant-1 (Figure 1A). The differential statistical response observed in the variable of number of fruits per plant indicates that most of the hybrids produced a very similar number of fruits. Except for the hybrids AN-104, AN-301, AN-304, AN-303 and AN-404, all of them were surpassed by more than 65% by the hybrid AN-401 (Figure 1B), which stood out among those of best response under the conditions of assessment under shade cloth. In the average fruit weight, significant statistical responses were observed between the hybrids tested, and the hybrid AN-203 stands out for this variable, followed by AN-302, AN-402 and AN-304, although the hybrids AN-103, AN-201, AN-204, AN-401, AN-401 and AN-403 are also in the same statistical group; in addition, the hybrid AN-203 exceeded by more than 35% the hybrids that statistically produced the fruits with least mean weight (Figure 1C).

According to Tukey's means test $p \leq 0.05$, significant statistical differences were observed in the variable of fruit length, where the hybrids that produced the shortest fruits were AN-102, AN-101, AN-201, AN-203, AN-202, AN-301 and AN-303; the rest of the hybrids showed a similar statistical response, although higher than those mentioned before (Figure 1D). It is important to point out that the fruit length is of utmost importance,

since this variable is defining for the destination market and generally fruits of 17-18 cm are preferred, ranges where most of the hybrids tested were found. On the other hand, in the variable of basal width of the fruit, statistical differences were observed according to Tukey's means test $p \leq 0.05$, where the hybrid AN-302 produced the widest fruits in their basal part close to the peduncle; while the fruits of less width in the base were produced by the hybrid AN-404, in the rest of the hybrids a trend was observed of intermediate response among the ones mentioned before (Figure 1E), although the hybrid AN-302 exceeded by more than 10% all the hybrids tested. In the variable of width of the central part of the fruit, significant statistical differences were also detected according to Tukey's mean test $p \leq 0.05$, where similar to the width of the base, the hybrid AN-302 produced the widest fruits at the center part, although in the same statistical group there were the hybrids AN-103, AN-104, AN-204, AN-202, AN-302, AN-304, AN-401, AN-402 and AN-403; meanwhile, the fruits of less width at center were produced by the hybrids AN-404, AN-301, AN-101 and AN-102 (Figure 1F). The differential statistical response observed between the hybrids, in the yield variables and components, is attributed to the genetics of each hybrid, in response to the combination of two different parents (Pech *et al.*, 2010), since when they are cultivated in the same site and under the same conditions of shade cloth, the uniformity of the assessment environment is assumed except for the soil, and what is expressed is the genetic differences of each material (Rangnamei *et al.*, 2017). This translates into its phenotypic performance in response to the environmental condition under which they develop (Loatournerie *et al.*, 2015; Maboko and Du Plooy, 2018), allowing to clearly identify the hybrids of greatest potential for those response variables. Combined with adequate management practices under conditions of shade cloth, they could increase their productive potential and the cultivation cycle could be prolonged allowing more trade windows; however, the yield produced by each plant is of greater importance when new materials, hybrids or varieties are tested (Echandi, 2005). In addition, the yield is a good indication of the genetic potential of a hybrid, since such a variable is related with the response of tolerance of plants to adverse factors of biotic and abiotic type and in the best of cases to new agroclimatic conditions or specific environments (Zewdie and Bosland, 2000). Although the new perspectives indicate that the generation of hybrids is accelerated and could be more accurate when combining traditional techniques of genetic improvement with the biotechnology of molecular markers (Nar, 2023), it is the presence of the consumer which in the end determines the genetic material that is produced and traded (Goldman *et al.*, 2023). Outstanding experimental hybrids ought to be tested in different producing areas of the country, with the aim of corroborating their stability, productivity and quality (Zewdie and Bosland, 2000), for the farmers to validate such results and so that they can be eventually produced and traded in those regions.

In the trait of calyx depth, differential statistical responses between the hybrids tested were observed, where excepting the hybrids AN-101, AN-202, AN-302, AN-303, and AN-404, the other hybrids showed a statistically similar behavior for that variable (Figure 2A), where AN-201 surpassed by up to 45% the hybrids that produced the fruits with lowest calyx depth. This response variable is of great importance, since the calyx depth

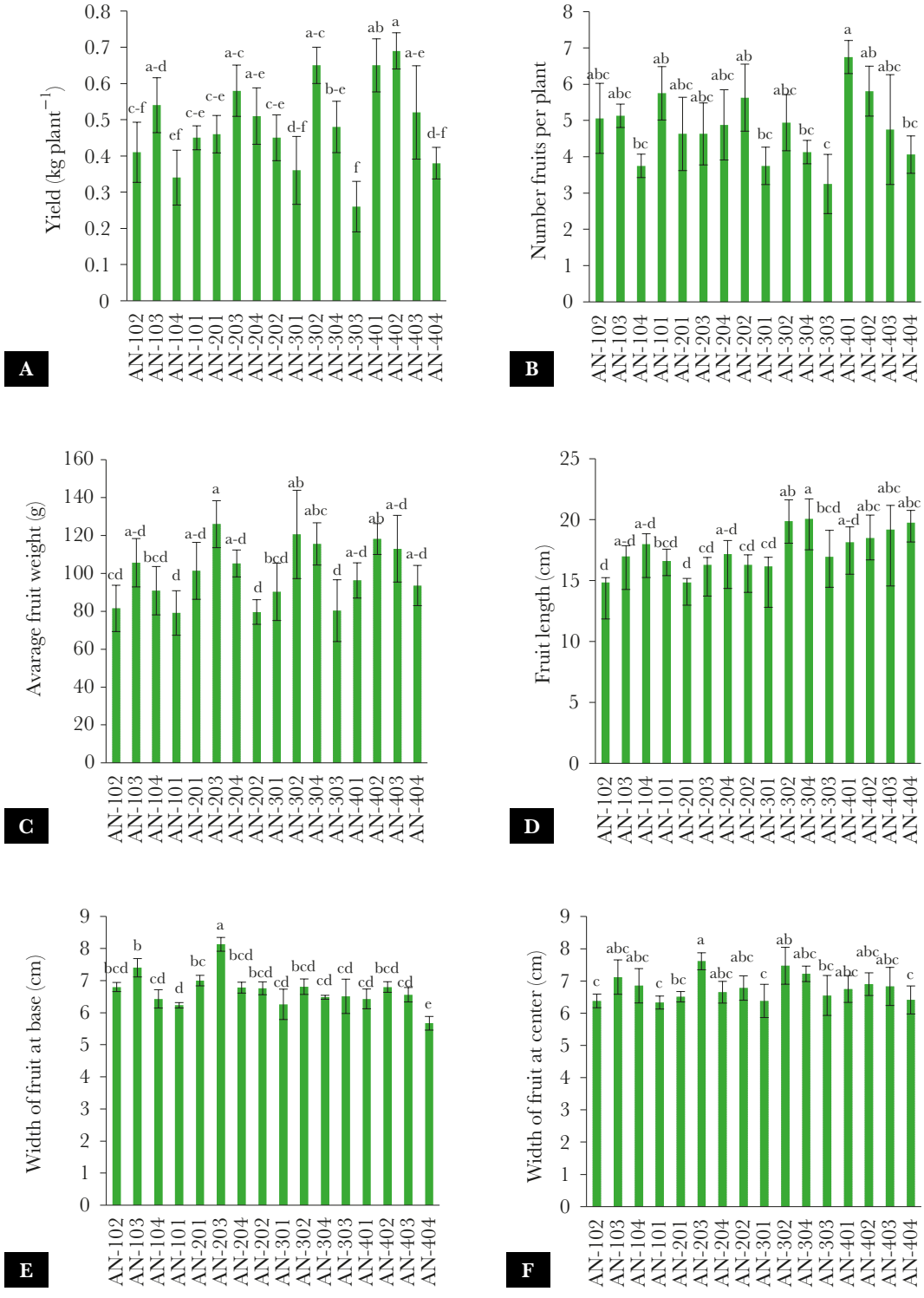

Figure 1. Response of the experimental hybrids of poblano pepper in the yield (A), number of fruits per plant (B), average weight of the fruit (C), fruit length (D), width of the fruit at base (E), and width of the fruit at center (F). ANVA $p \leq 0.05$, Tukey's means test ($p \leq 0.05$), vertical bars corresponded to standard deviation.

is generally asociated with a better fruit quality; however, a greater calyx depth is directly related with the proliferation of pathogens in zones of high frequency of precipitation, induced by the water accumulation in that structure. In length of fruit peduncle, statistical differences were also detected according to Tukey's means test p≤0.05, where except for the hybrids AN-202, AN-201, AN-102 and AN-204, the rest of the hybrids showed a statistically similar behavior although higher than the ones cited before (Figure 2B). Regarding this variable, it is important to mention that as the fruit length peduncle increases the harvesting tasks are eased, although it is also associated with the fall of fruits when frequent tasks are carried out in the crop, particularly tutoring. The differential statistical response (Tukey p≤0.05), observed in the variable final height of the plant

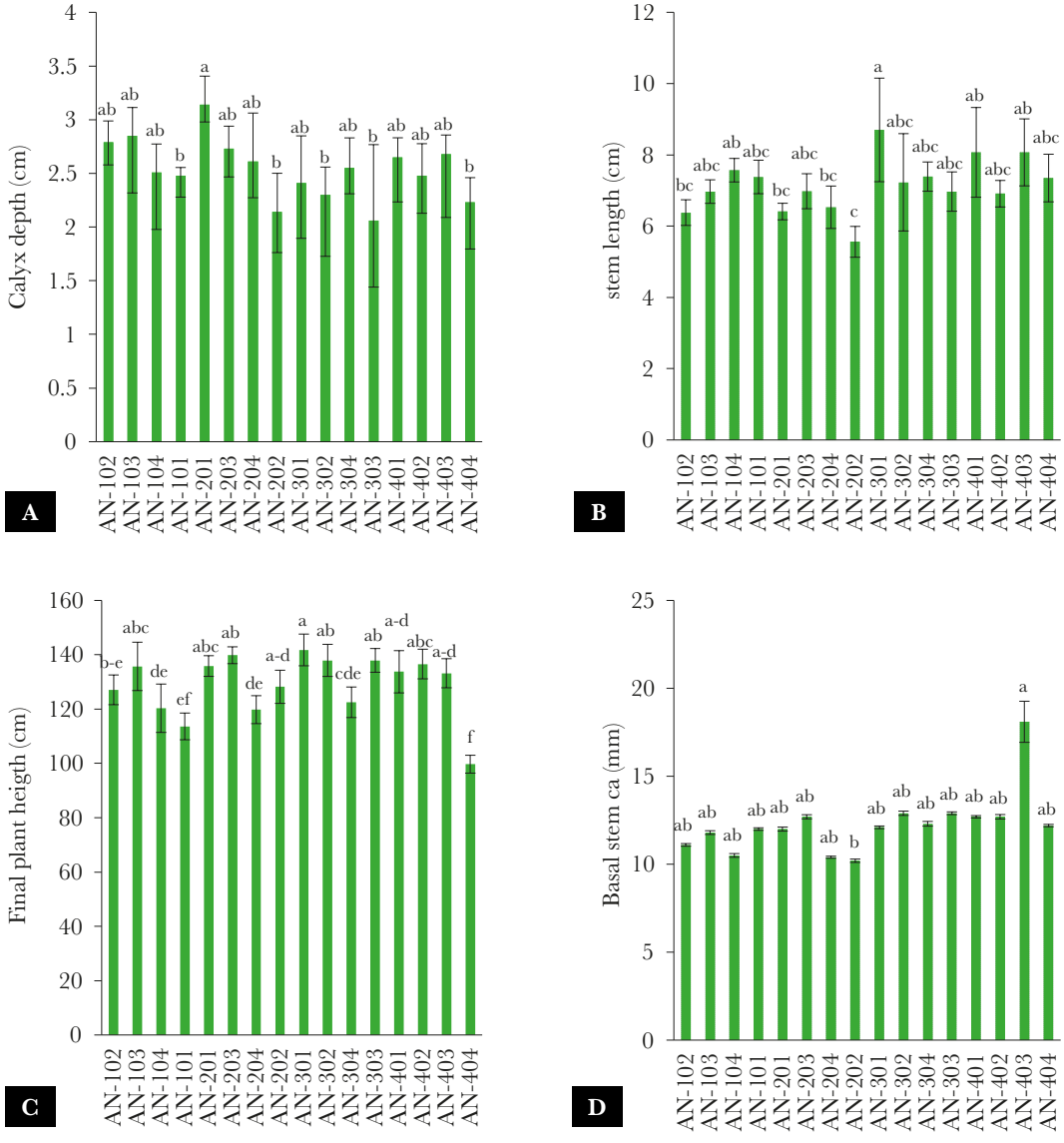

Figure 2. Response of the experimental hybrids of poblano pepper in the calyx depth (A), length of the peduncle (B), final height of the plant (C), basal stem thickness (D). ANVA p≤0.05, Tukey's means test (p≤0.05), vertical bars correspond to standard deviation.

indicates that the hybrids behaved differently under the conditions tested, with the hybrids AN-301, AN-302, AN-303, AN-401, AN-402, AN-403, AN-201, AN-203 and AN-103 being higher than the rest, while the hybrid of lowest final height of the plant was the hybrid AN-404. Likewise, the differential statistical response (Tukey $p \leq 0.05$), showed by the variable of basal stem thickness, indicates that with the exception of the hybrid AN-202, all the hybrids showed a similar reponse under to conditions tested, although the hybrid that stands out among all of them is AN-403. The plant height and the stem thickness are two indicators of the plant vigor, and they are generally associated with the final productivity, so it is important to consider them at the time of choosing a hybrid for commercial production.

Table 4 shows, from Pearson's coefficients of correlation, that the number of fruits per plant, average weight of the fruit and width at center of the fruit, are the traits that influence most in a positive way in the yield of poblano pepper with correlations of 0.74, 0.55 and 0.44, respectively, and similar trends are reported by Parvin and Arifuzzaman (2023). Therefore, these traits must be considered by farmers at the time of choosing or selecting new varieties or hybrids for their agricultural areas, although the stem thickness and the plant height also collaborate with 0.25 and 0.24. The width at center of the fruit, fruit length, and basal width of the fruit are the variables that most contributed in the accumulation of average weight of the fruit with 0.63, 0.49 and 0.44, respectively; without a doubt, these are parameters to take seriously into consideration when new hybrids or varieties are selected. The basal width of the fruit is related positively with the plant height with 0.53 of positive correlation; that is, with a greater plant height the fruit is wider, or at least in the hybrids and the conditions tested. The fruit length is negatively correlated with the basal width of the fruit with −0.29, which indicates that as the fruit becomes longer its width decreases. The stem thickness is associated with the length of the peduncle with 0.35 of positive correlation.

Table 4. Pearson's coefficient of correlation of variables evaluated in poblano pepper grown under shade cloth.

	Yield	NFP	AFW	FL	WBF	ACF	CD	PL	FHP
NFP	0.74**								
AFW	0.55**	−0.13							
FL	0.25	−0.11	0.49**						
WBF	0.36**	0.09	0.44**	−0.29*					
WCF	0.44**	0.03	0.63**	0.39**	0.62*				
CD	0.20	0.09	0.20	−0.2	0.35*	0.08			
PL	0.04	−0.09	0.17	0.21	−0.13	0.08	0.11		
FPH	0.24*	0.04	0.25*	−0.16	0.53*	0.25*	0.12	0.09	
TBS	0.26*	0.16	0.15	0.18	−0.02	0.10	−0.01	0.35*	0.19

*=significant ≤0.05, **=highly significant $p \leq 0.01$. Yield=Yield, NFP=Number of fruits per plant, AFW=Average fruit weight, FL=Fruit length, WBF=Width at base of the fruit, WCF=Width at center of the fruit, CD=Calyx depth, PL=Peduncle length, FPH=Final plant height, and TBS=Thickness of basal stem.

CONCLUSIONS

The agronomic response of the experimental hybrids tested under shade cloth was variable in most of the variables evaluated, so a different genetic potential is inferred in each one of them, in response to the conditions of shade cloth under which they developed. The hybrids that showed a favorable agronomic response in most of the attributes evaluated were AN-401, AN-402, AN-203, AN-302.

In poblano pepper, the variables that most contributed to the yield are the number of fruits per plant, average weight of the fruit, width of the fruits at the base and the center, and to a lesser extent the stem thickness and plant height.

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