Revista Mexicana de Ciencias Agrícolas

REMEXCA

DOI: https://doi.org/10.29312/remexca.v15i8.3021

Article

Agronomic performance of four poblano chili genotypes in the open field in southeastern Coahuila

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Abstract

The present study aimed to evaluate the yield, yield components, and morphological attributes of four landrace genotypes of poblano chili in the open field in southeastern Coahuila, genotypes one and two (G1 and G2) collected from the state of Puebla, genotype three (G3) from Zacatecas, and genotype 4 (G4) from Jalisco, in order to identify their potential for genetic improvement. The experimental design and statistical model used was completely randomized with four replications each and the Anova at *p#* 0.05. The results indicate significant differences in most of the variables evaluated, except for yield and fruit tip width. In number of fruits per plant, the best performance was observed in genotypes two and one, with 10.25 and 7.92 fruits per plant, respectively; in average fruit weight and fruit length, genotype three was superior, with 104.54 g and 15.05 cm, respectively. In base width, fruit center width, and plant height, the best performance was shown by genotypes two and three. The results obtained assume the existence of genetic variability in the genotypes and allowed us to identify genotype three as having the best performance and genetic potential for fresh marketing; by the number of fruits per plant, genotypes two and one had the best performance. Due to the conservation of the characteristics in dehydrated fruit, visual appearance, color and consistency, it is inferred that genotypes one and two have greater potential for marketing as dehydrated fruit 'ancho'.

Keywords:

Capsicum annuum, adaptation, genetic improvement, yield.

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Introduction

Chili (*Capsicum annuum* L.) is one of the crops native to Mexico; Olvera *et al*. (1998) mention that it was cultivated from 7 000 to 2 555 BC in Puebla and Tamaulipas. Among the most cultivated breeds in Mexico are jalapeño, serrano, and poblano chilies (SIAP, 2020). The production of this crop is a fundamental part of the local, regional, and national economy due to the generation of economic income through national consumption and export, positioning it as one of the most important crops in Mexico (Huerta *et al*., 2007).

In Mexico, in the 2020 agricultural year, the area sown with green poblano chili was 16 822 ha, of which 16 234 correspond to open field production and 557 to greenhouse production, with a production of 419 403 t and an average yield of 25.05 t ha^{-1}; 70 ha are sown in Coahuila, with an average yield of 19 t ha^{-1} (SIAP, 2020). The importance of this chili lies in its forms of commercialization, either as 'poblano chili' or dehydrated as 'ancho chili'.

Zacatecas, Guanajuato, and Sinaloa lead the production of poblano chili, and Zacatecas and San Luis Potosí lead the production of ancho chili (SIAP, 2020). However, competition with other countries generates pressure on Mexican producers to produce high-quality fruits (Truong *et al*., 2011). However, problems such as susceptibility to pests and diseases, as well as current extreme environmental changes, are factors that prevent quality production from being obtained and it impacts the economy, mainly of small farmers (Joukhadar and Walker, 2020).

Another problem that causes low yields and loss of quality is the use of landrace seeds since approximately 80% of the area is cultivated with this type of seed (Marín *et al*., 2013). The lack of advice to small producers, the proliferation of new viral and fungal diseases, which derive from the use and poor selection of seed obtained from their own crops, also have an impact (Macías *et al*., 2009).

Their cultivation is also limited by lack of economic resources, high input costs, variable harvest prices, poor marketing, scarcity of labor and water resources, which has worsened with climate change (Galindo *et al*., 2002). Therefore, in the face of the current environmental changes that are occurring in Mexico and the world, it is necessary to conserve plant genetic resources since the protection of this genetic wealth allows its use for improvement and adaptation to new environmental conditions; in this sense, the generation of new improved varieties with greater genetic potential and better performance in the environment where they are grown is promoted (Hartmann and Kester, 1985), in order to produce better quality fruits that meet the standards required by the market and that contribute to the sustainability of agricultural systems to extend their production area to other regions where there is not production or production was stopped (Aguilar *et al*., 2010; Aguirre and Muñoz, 2015; Camarena *et al*., 2014).

The aforementioned problems lead to the objective that was to evaluate the agronomic performance of four landrace genotypes of poblano chili collected from small farmers in the states of Puebla, Jalisco and Zacatecas, in the southeast of Coahuila in order to identify their genetic potential to include them in breeding programs.

Materials and methods

Location of the experimental site

This research work was conducted in the 2020 summer-autumn cycle in the El Bajío Experimental Field of the Antonio Narro Autonomous Agrarian University in Saltillo, Coahuila, Mexico, which is located at the geographical coordinates 101° 02' 14" west longitude and 25° 21' 35" north latitude, at an altitude of 1 743 m, with an average annual temperature of 16.9 °C and average annual rainfall of 435 mm.

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Genetic material

Landrace seeds of four poblano chili genotypes were used (Table 1). Genotype one (G1) and genotype two (G2) were collected in the municipality of San Martín Texmelucan in the state of Puebla, genotype three (G3) in Villa de Cos, Zacatecas and genotype 4 (G4) in Tomatlán, Jalisco in 2019.

Table 1. Origin of the four landrace genotypes of poblano chili evaluated in the open field in the southeast of Coahuila.

ID	Color at maturity	Municipality	State	Coordinates	Altitude (m)
G1	Brown	San Martin Texmelucan	Puebla	19°17’00” N 98°26’00” W	2 300
G2	Brown	San Martin Texmelucan	Puebla	19°17’00” N 98°26’00” W	2 300
G3	Red	Villa de Cos	Zacatecas	23°17’42” N 102°20’24” W	1 980
G4	Brown	Tomatlán	Jalisco	19°56’00” N 105°14’00” W	50

G= genotype.

Seedling production

The four genotypes were sown in 200-cavity polystyrene trays, using a mixture of peat moss (Premier®) and perlite (Termilita®) in a proportion of 70/30%, respectively, as germination substrate. Once emerged, seedlings were fertilized with triple 20 (20-20-20) of soluble N-P_2O_5-K_2O at a rate of 0.4 g L^{-1} at 6 days after emergence (DAE), 0.6 g L^{-1} at 15 DAE, 0.8 g L^{-1} at 30 DAE, and 1 g L^{-1} at 45 DAE.

Field establishment and crop management

The transplant was carried out 60 days after sowing and was in a loam soil with the following characteristics: bulk density 1.25 g cm^{-3}, pH 1:2 alkaline 8.61, total carbonates 8.25%, electrical conductivity 1.1 dS m^{-1}, saturation point 40%, field capacity 21.3%, permanent wilting point 12.7%, macronutrients (N-NO^{3-} 39.7, P-Olsen 65, S 55.9, Cl not determined, K^+ 658, Ca^{2+} 3995, and Mg^{2+} 321 ppm), microelements (Fe^{3+} 2.07, Mn^{2+} 3.11, $B3^+$ 1.31, Zn^{2+} 4.95, Mo^{2+} not determined, and Cu^+ 0.51 ppm). Each genotype was distributed in a raised growing bed (25 cm high by 30 cm wide and 25 m long) without mulch; the distance between beds was 1.8 m and the distance between plants within the beds was 30 cm, in a double row with distance between rows of 20 cm, for a calculated population density of 37 000 plants ha^{-1}. The plants were arranged under a completely randomized experimental arrangement with four treatments and four replications each; each replication with four measurable useful plants prostrate to the center with full competence with a total of 12 plants per replication.

The crop was fertigated three times a week with an overall fertilization of N-P-K of 475, 339, and 200 kg ha^{-1}. A daily irrigation was applied; the irrigation water contained the following characteristics (pH 7.5, electrical conductivity 1.15 dS m^{-1}, sodium absorption ratio 1.61, and HCO_3^- 7.56), macroelement content (NO_3^- 0.41, $H_2PO_4^-$ not determined, SO_4^{2-} 1.61, Cl^- 2.2, K^+ 0.1, Ca^{2+} 5.57, Mg^{2+} 2.42, and Na^+ 3.22 milliequivalents L^{-1}) and microelement content (Fe^{3+} 0.0118, Mn^{2+} 0.0047, B^{3+} 0.4, Zn^{2+} 0.0891, and Cu^+ 0.0122 parts per million L^{-1}).

The duration of irrigation was 1 h and the expenditure of each dripper was 0.5 L h^{-1}, with distances between drippers of 20 cm. To prevent and control whitefly (*Bemisia tabaci*), thrips (*Frankliniella occidentalis), and paratrioza (Bactericera cockerelli), applications of 15.3% Spirotetramat, 23.1% Spiromesifen, and 17% Imidacloprid + 12% betacyflutrin were made at a rate of 1 ml L-1.*

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Determination of agronomic performance variables

Three harvests were carried out; the first was at 90 days after transplantation (DAT), the second at 112 and the third at 127. To obtain the yield in grams per plant, the yields obtained in the three harvests were added together, for which an OHAUS® Scout-pro® digital scale was used; at the same time, the number of fruits per plant (NFP) was counted; to calculate the average fruit weight (AFW), the total yield of each plant was divided by the total number of fruits of that plant.

Fruit length (LF) expressed in centimeters was determined with a Truper® vernier, which was also used to measure width at the base (BW), width at the center (CW), width at the tip of the fruit (TW), and depth of the calyx, all expressed in millimeters; they were quantified in fresh and dehydrated fruit; the fresh fruits were dehydrated inside blotting paper bags under greenhouse for 30 days. A Truper® tape measure graduated in centimeters was used to measure the height to the first fork, total plant height, as well as the length and width of the leaf.

Determination of the percentage of conservation of characteristics of the dehydrated fruit from the first two harvests

The percentage of conservation of the characteristics of the dehydrated fruit was determined in average fruit weight, fruit length, base width, width in the center and width at the tip of the fruit and four fruits chosen randomly were used for each replication and they were quantified in the fresh fruits, 'poblano', as well as in the dehydrated fruit, 'ancho', in the first and second harvests, and it was calculated as follows.

$$\%\ \text{conservation of the trait of the dehydrated fruit} = \frac{\text{Value of the dehydrated trait}}{\text{Value of the fresh trait}} * 100$$

Statistical analysis of the data

The Anova of the data collected and analyzed was at $p \leq 0.05$ and the mean test was by Tukey ($p \leq 0.05$) and the statistical program of InfoStat® version 2019 was used.

Results and discussion

Agronomic performance of genotypes

The analysis of variance ($p \leq 0.05$) and Tukey's mean test ($p \leq 0.05$) did not detect statistical differences in fruit yield (g plant^{-1}) in the genotypes (Figure 1A), so that all genotypes have a similar performance under the evaluation conditions; however, if the yield per plant is extrapolated to tons per hectare, considering the planting density of approximately 37 000 plants ha^{-1}, G2 has average yields of 22.69 t ha^{-1} and G3 of 20.06.

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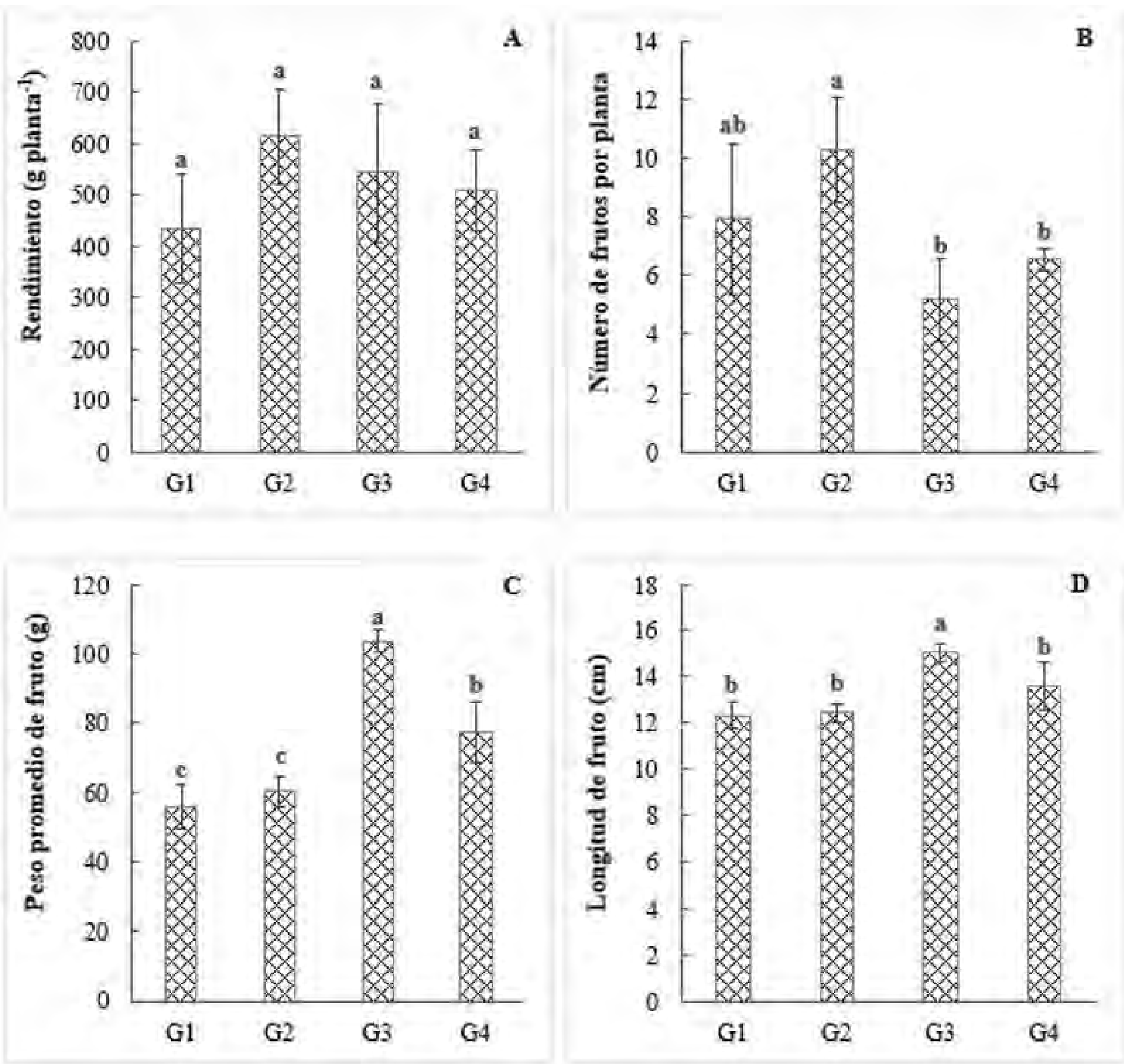
Figure 1. Anova *p*≤ 0.05 and Tukey's mean test *p*≤ 0.05 of yield in grams per plant (A); number of fruits per plant (B); average fruit weight (C) and fruit length (D), of four poblano chili genotypes evaluated in the open field in southeastern Coahuila. Vertical bars correspond to the standard deviation.



In this sense, Ramos *et al*. (2011) reported average yields of 16.23 t ha^{-1} in the poblano chili hybrid called Vencedor, while Zermeño *et al*. (2019) obtained 6.2 t ha^{-1} in the Ébano variety, lower yields in relation to what was exposed by the genotypes evaluated considering that the seed is landrace, but similar and competitive to the 19 t ha^{-1} reported in the state of Coahuila and the 25 t ha^{-1} on average in the country; nevertheless, up to 40 t ha^{-1} are produced under fertigation conditions, and up to 80 t ha^{-1} under protected agriculture (SIAP, 2020).

For the number of fruits per plant, G2 and G1 collected in the state of Puebla stand out statistically, with 10.25 and 7.92 fruits per plant, respectively (Figure 1B), so it is inferred that they could have good adaptability for the expression of this trait in the region of Coahuila. Toledo *et al*. (2011) reported 3.4 to 5.9 fruits per plant in the 10 best native varieties of poblano chili evaluated.

Similarly, Zermeño *et al*. (2019) reported average values of 6.6 fruits per plant, which are lower than the genotypes of the state of Puebla, but similar to the G3 of Zacatecas and G4 of Jalisco. On the other hand, there were significant statistical differences in average fruit weight, where the best performance was shown by G3 with 104.54 g, those with the lowest weight correspond to G1 and G2. G4 was intermediate with 77.36 g (Figure 1C).

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In this regard, Kirk *et al*. (2013) reported poblano chili fruits with weights of 54.3 to 67.9 g and Zermeño *et al*. (2019), a weight of 25.33 g. For their part, Toledo *et al*. (2011) indicated from 5 to 24.8 g, where seven were native varieties, these reported data are lower than those found in G3 and G4, which indicates the genetic potential of these genotypes. Fruit length had a differential statistical response (Figure 1D), with G3 having the best performance with 15.05 cm; due to the expression of this trait and the higher average fruit weight, it is inferred that it could have great potential for marketing in fresh green or 'poblano'; the rest of the genotypes showed a similar statistical behavior.

In reference to fruit length, Kirk *et al*. (2013) obtained fruits of 8.43 to 11 cm; Santiago *et al*. (2018) reported 14.9 cm in the mulato-type ancho chili hybrid (HAM14F) and Zermeño *et al*. (2019) obtained fruits of 7.16 cm in length. It is important to note that this characteristic is of great importance for commercialization and as it is landrace seed, the results are acceptable and they could eventually compete with varieties or hybrids.

The differences observed in the agronomic performance of the genotypes, in some of the traits evaluated, are attributed to the geographical origin and the genetics of these genotypes, characteristics that could be improved through selection and inbreeding (Pech *et al*., 2010); nonetheless, the test environment also determines the expression of the observed phenotypic characteristics; therefore, it is important to consider their interaction (Latournerie *et al*., 2015).

These differences could provide guidelines for the selection of promising genotypes with the best phenotypic characteristics and including them in genetic improvement programs for the generation of varieties adapted to new agroclimatic conditions or specific environments (Zewdie and Bosland, 2000; Echandi, 2005). In addition, the existing genetic diversity and divergence would also allow us to exploit the phenomenon of heterosis in the generation of hybrids (Moses and Umaharan, 2012).

The traits of base width, center width, and calyx depth of the fresh fruit had a differential statistical response (Anova $p\leq 0.05$) (Table 2), where G2 and G3 were superior for the base width variable with 63.09 and 58.13 mm, respectively and center width of 59.67 and 55.51 mm, respectively for tip width, there were no differences. In this regard, Kadri *et al*. (2009) point out that 54.3% of the total variation in fruit diameter is due to the genotypes themselves.

Table 2. Base width, center width, tip width, and calyx depth of the fruits of four poblano chili genotypes evaluated in southeastern Coahuila.

Genotypes	Base width (mm)	Center width (mm)	Tip width (mm)	Calyx depth (mm)
G1	50.15 b[&]	50.04 b	26.94 a	19.69 a
G2	58.13 a	55.51 a	28.66 a	20.05 a
G3	63.09 a	59.67 a	26.99 a	21.25 a
G4	47.31 b	48.56 b	24.53 a	8.94 b
Anova *p*#	0.0001	0.0001	0.0756	0.0001
CV (%)	4.68	4.27	7.4	12.61
LSD	5.36	4.78	4.15	4.62

[&] = means with the same letter in the columns are statistically equal (Tukey $p\leq 0.05$). CV= coefficient of variation; LSD= least significant difference (Tukey $p\leq 0.05$).

Similarly, Kirk *et al*. (2013) obtained fruits with center widths of 53.4 to 57.3 mm, being values close to those obtained in this research. For its part, in calyx depth, the statistical response was similar in G3, G2, and G1, with values of 21.25, 20.05, and 19.69 mm, respectively. Calyx depth is a variable that has a close positive relationship with fruit weight.

There were statistically significant differences in the variables of plant height, height to the first fork, and leaf length and width according to the Anova $p\leq 0.05$ and Tukey $p\leq 0.05$ (Table 3). G2 and G3 stood out in plant height with 89.18 and 89.88 cm, while G4 presented smaller and more compact plants with 62.78 cm. Toledo et al. (2011) reported plant heights of lower magnitude (37.9 to 56.8) in 49 varieties of chili.

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Table 3. Agronomic behavior variables evaluated in the four genotypes of poblano chili in the southeast of Coahuila.

Genotypes	Plant height (cm)	Height to the first fork (cm)	Leaf length (cm)	Leaf width (cm)
G1	76.35 b[&]	21.07 ab	7.48 b	3.52 b
G2	89.18 a	15.3 b	9.24 a	4.46 a
G3	89.88 a	25.5 a	8.85 ab	4.77 a
G4	62.78 c	14.18 b	9.4 a	4.49 a
Anova *p*≤	0.0093	0.0032	0.0093	0.0083
CV (%)	6.6	19.51	8.13	10.09
LSD	11.02	7.78	1.49	0.91

[&] = means with the same letter in the columns are statistically equal (Tukey $p\leq 0.05$). CV= coefficient of variation; LSD= least significant difference (Tukey $p\leq 0.05$).

In this sense, Linares (2004) determined that larger and more vigorous plants generally produce better yields, a trend that was observed in this research work. In height to the first fork, G3 and G1 were superior, with 25.5 and 21.07 cm, respectively. In relation to the above, Toledo *et al*. (2016) assures that the size of the plant must be adequate to be able to support the load and size of the fruits, quality and uniformity, since if the fruits are in direct contact with the soil, they deform or lose marketing quality.

In terms of leaf length and width, a similar statistical behavior was observed between G4, G2, and G3; in this sense, the importance of a good leaf surface and cover lay in its ability to intercept the greatest amount of photosynthetically active radiation to transform into photoassimilates, which translates into an increase in the quality of fruits and therefore in the final yield of the crops; likewise, it avoids the so-called burns caused by direct solar radiation to the fruits (Mendoza *et al*., 2017).

Authors such as Santiago *et al*. (2018) reported a hybrid of mulato ancho chili with leaf sizes 9.49 cm long and 4.42 cm wide, similar to those obtained by G3 and G4 in this research. It is important to note that, based on agronomic and morphological variables, it has been possible to characterize *Capsicum* species with good adaptation and production potential for use in different regions (Sudre *et al*., 2010).

Characteristics of fresh and dehydrated fruit from the first two harvests

In addition to the data presented previously, the Anova $p\leq 0.05$ and Tukey's mean test (*p*# 0.05) of some of the characteristics of the fresh and dehydrated fruit from the first two harvests are also shown and are presented in Table 4. The average weight and length of fresh fruit were higher in genotypes three and four.

Table 4. Analysis of variance and comparison of means of characteristics of fresh and dehydrated fruit in the first two harvests.

Genotypes	Average fruit weight (g)	Fruit length (cm)	Base width (mm)	Center width (mm)	Tip width (mm)
			Fresh fruit characteristics		
G1	65.86 b[&]	12.7 b	51 b	50.03 c	27.42 a
G2	85.15 b	13.37 b	59.52 a	56.63 b	30.02 a

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Genotypes	Average fruit weight (g)	Fruit length (cm)	Base width (mm)	Center width (mm)	Tip width (mm)
G3	111.2 a	15.2 a	63.41 a	61.24 a	27.18 a
G4	110.98 a	14.61 a	51.78 b	52.76 bc	26.69 a
Anova *p*≤	0.0001	0.0001	0.0001	0.0001	0.1467
CV (%)	11.53	3.95	4.35	3.9	7.31
LSD	22.56	1.15	5.15	4.51	4.26
		Dehydrated fruit characteristics			
G1	7.96 b	9.76 c	43.38 ab	40.54 b	24.53 a
G2	9.36 ab	10.75 bc	48.22 a	46.85 a	35.22 a
G3	10.24 a	11.89 a	44.03 ab	36.57 b	20 b
G4	9.41 ab	11.37 ab	40.75 b	36.84 b	19.82 b
Anova *p*≤	0.0046	0.0003	0.0663	0.0002	0.0009
CV (%)	7.54	4.48	7.95	6.19	7.69
LSD	1.46	1.02	7.35	5.22	3.61

[&] = means with the same letter in the columns are statistically equal (Tukey $p \leq 0.05$); CV= coefficient of variation; LSD= least significant difference (Tukey $p \leq 0.05$).

Fruit base width was higher in genotypes three and two, while genotype three stood out in center width. Regarding the traits of the already dehydrated fruits, for the variable of average fruit weight, the response was statistically similar between G3, G4, and G2. The fruit length was higher in G3 and G4. Fruit base width showed a similar behavior between G2, G3, and G1, while G3 stood out in center width.

Percentage of preservation of fruit characteristics after dehydration in the first two harvests

A characteristic of the poblano chili is that it can be marketed fresh or dehydrated; therefore, it is important to quantify these characteristics to determine the percentage relationship between the traits of the dehydrated fruit and the fresh fruit. In this sense, derived from the first two harvests, in the variable of average fruit weight, the genotypes that retained the highest weight after dehydration were G1 and G2, with 12.09 and 10.99%, respectively (Table 5).

Table 5. Percentage (%) of preservation of dehydrated fruit characteristics in four poblano chili genotypes evaluated in the southeast of Coahuila.

Genotypes	Average fruit weight	Fruit length	Base width	Center width	Tip width
G1	12.09	76.85	85.06	81.03	89.46
G2	10.99	80.4	81.01	82.73	84.01
G3	9.21	78.22	69.44	59.72	73.58
G4	8.48	77.82	78.7	69.83	74.26

Fruit length was preserved in 80.4% in G2; the other genotypes varied between 76.85 and 78.22%. In contrast, in the width of the base, center, and tip of the fruit, the genotypes that retained more than 80% of their value were G1 and G2; with the results described above, added to the visual appearance, color, and consistency of the fruits (Figure 2), it is inferred that G1 and G2 have greater potential for the dehydrated fruit and G3 and G4 for fresh fruit.

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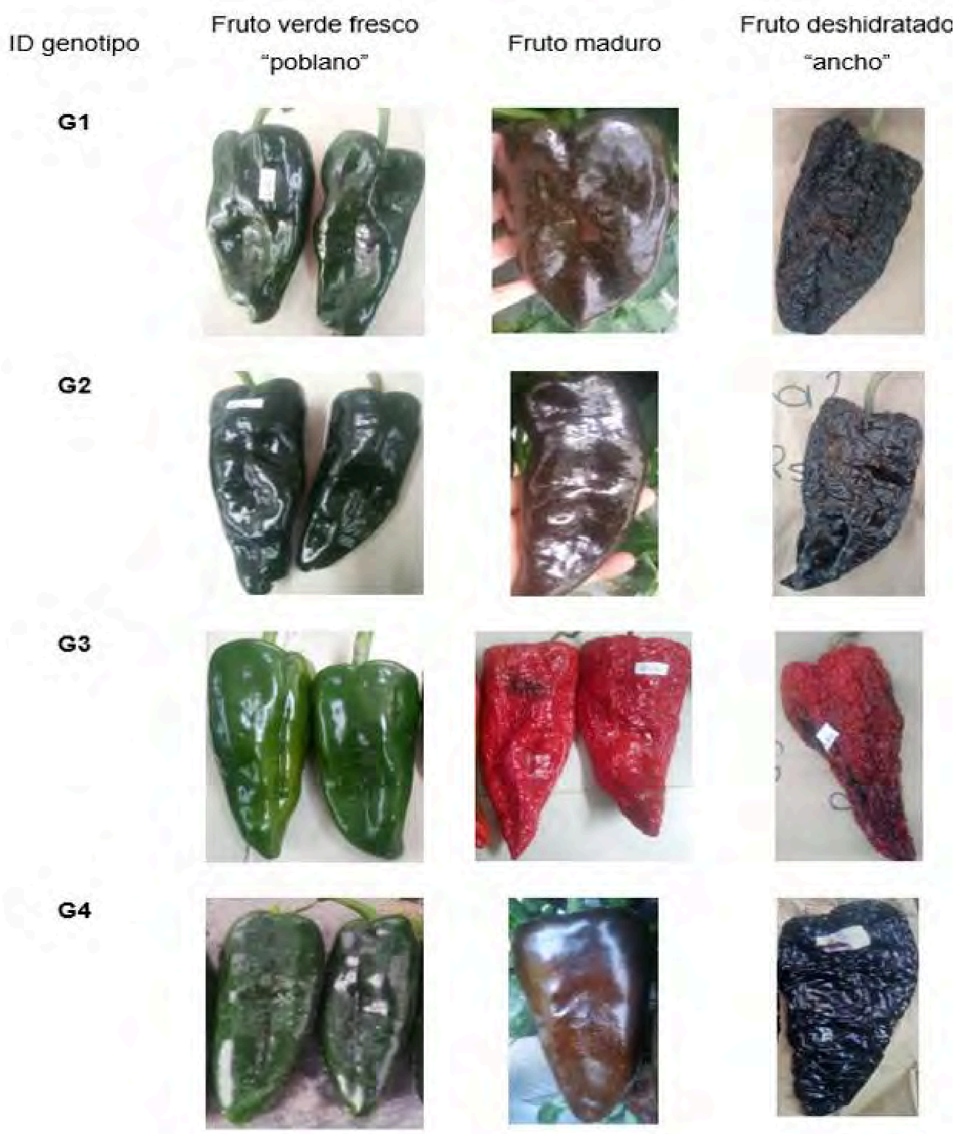
Figure 2. Fresh fruits 'poblano', ripe fruits, and dehydrated fruits 'ancho' from four poblano chili genotypes evaluated in the southeast of Coahuila.



The results found in the agronomic performance express the genetic variability in the genotypes of poblano chili, variability that is attributed to their geographical origin; this variability could be used to initiate a genetic improvement program and, in the medium or long term, generate improved varieties that meet the needs of producers and consumers, both fresh 'poblano' and dehydrated product 'ancho', and thus be able to extend the production area of this crop to other regions of the country, such as Coahuila.

Conclusions

The agronomic performance of the poblano chili genotypes tested in the southeast of Coahuila was variable; however, due to a greater length and average weight of fruit, G3 is the one with the best performance, and therefore, greater genetic potential for its commercialization fresh or as 'poblano', followed by G4. By the number of fruits harvested per plant, the genotypes with the best performance and genetic potential were G2 and G1. Due to the higher percentage of conservation

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of the characteristics quantified in the dehydrated fruit, added to the visual appearance, color, and consistency, it is inferred that G1 and G2 are the ones with the best performance, and therefore, those of the greatest genetic potential for marketing as dehydrated fruits or 'ancho'.

The results found in the agronomic performance suggest the existence of genetic variability in the poblano chili genotypes tested in the state of Coahuila, variability that is attributed to their geographical origin and to the genetics of each one.

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DOI: https://doi.org/10.29312/remexca.v15i8.3021

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Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 September 2024
Date accepted: 01 November 2024
Publication date: 15 December 2024
Publication date: Nov-Dec 2024
Volume: 15
Issue: 8
Electronic Location Identifier: e3021
DOI: 10.29312/remexca.v15i8.3021

Categories

Subject: Articles

Keywords:

Keywords:

Capsicum annuum
adaptation
genetic improvement
yield

Counts

Figures: 2
Tables: 5
Equations: 2
References: 27
Pages: 0