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Yield and adaptability in corn genotypes evaluated in the northern region of Tamaulipas, Mexico

Hernández-Martínez, Rosendo[1*]; Reyes-Méndez, César A.[2]; Ruiz-Ramírez, Santiago[3,6]; Valdez-Hernández, Miguel A.[2]; Velázquez-Martínez, Mauricio[4*]; Alfaro-Martínez, Liliana G.[5]

[1] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Las Huastecas, Carretera Tampico-Mante km. 55, Villa Cuauhtémoc, Altamira, Tamaulipas, México. C. P. 89603.
[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Río Bravo, Carretera Matamoros-Reynosa km 61, Río Bravo, Tamaulipas, México. C. P. 88900.
[3] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Centro-Altos de Jalisco. Av. Biodiversidad No 2470. Tepatitlán de Morelos, Jalisco, México. C. P. 47600.
[4] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental San Luis, Soledad de Graciano Sánchez, San Luis Potosí, México. C. P. 78431.
[5] Universidad Autónoma Chapingo, km 38.5 Carretera México-Texcoco, Texcoco, Estado de México. C. P. 56230.
[6] Colegio de Postgraduados, Campus San Luis Potosí, Salinas de Hidalgo, San Luis Potosí, México C. P. 78622.
* Correspondence: hernandez.rosendo@inifap.gob.mx; velazquez.mauricio@inifap.gob.mx

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ABSTRACT

Objective: To estimate the performance and adaptability parameters of simple corn hybrids in the northern region of Tamaulipas, Mexico.

Design/methodology/approach: During the 2022-2023 F-W agricultural cycle, 49 corn genotypes were evaluated across two environments in Tamaulipas. In both locations, experiments were conducted using a 7×7 lattice design with three replicates. The study variables included yield, plant and corncob height, days to male and female flowering, grain moisture, root and stem lodging, corncob appearance, and husk coverage. A combined analysis of variance was performed across locations.

Results: The study revealed significant differences among genotypes and environments for most variables, except for root and stem lodging. Regarding genotype × environment interaction, the only significant variable was grain moisture. The experimental hybrids GEN 34, GEN 15, GEN 16, and GEN 24 achieved yields above 8.4 t ha^{-1} and showed good adaptability compared to transnational materials. The evaluated agronomic characteristics indicated wide genetic diversity.

Limitations on study/implications: Water scarcity and high temperatures in the region limited the hybrids' ability to reach their maximum yield potential. The four outstanding hybrids are recommended for adoption in the northern region of Tamaulipas. The data generated are essential for guiding selection strategies in breeding programs and for facilitating the rapid development of new genotypes.

Keywords: *Zea mays* L., Hybrids, agronomic parameters, environments.

INTRODUCTION

In plant breeding programs, the final stage involves the evaluation of hybrids or varieties, from which those with the greatest yield potential and desirable agronomic traits are selected and commercialized. In Mexico, in 2024, a total of 6.5 million hectares of corn were planted, with a production of 18.2 million tons and an average yield of 3.6 t ha^{-1} (SIAP, 2025). Of the total corn area planted in the country, 75.0% corresponds to landraces or native varieties, while 25.0% corresponds to improved seed (Espinosa-Calderón *et al.*, 2012; Gaytán-Bautista *et al.*, 2009; Tadeo-Robledo *et al.*, 2015). However, the cost of hybrid seed is high across the different agroecological zones, with the additional limitation that it is marketed in packages of 60,000 seeds per hectare. For this reason, farmers seek alternatives from public institutions or research centers, in order to use their improved corn varieties with the objective of reducing production costs and, consequently, increasing profitability in agricultural production (Ramírez *et al.*, 2024). In this context, the contribution of geneticists in assessing grain yield and other agronomic parameters requires conducting field experiments that involve experimental hybrids, as well as including well-established genotypes in the market, which are used as checks (King *et al.*, 2024).

On the other hand, Duvick (2005) noted that evaluations of new hybrid combinations are frequently carried out by plant breeders to monitor progress in crop production and to estimate the genetic gain of each hybrid. Recently, several studies have evaluated different agronomic traits in a large number of corn hybrids, where hybrids or varieties with high yield potential are identified and selected, with the aim of releasing them commercially so that they can be adopted by farmers (García-Mendoza *et al.*, 2024; Hernández-Martínez *et al.*, 2024; Ni *et al.*, 2024; Sanaev *et al.*, 2024; Shojaei *et al.*, 2024). However, the materials under study differ in certain characteristics, such as their genetic origin, growth cycle, adaptability, and genetic response to climate and soil conditions (Andriienko *et al.*, 2024). Despite extensive research on the evaluation of corn genotypes, no ideal genotype exists for all agricultural regions, particularly when it comes to new hybrids. Therefore, conducting such studies in each region of interest is essential. For this reason, the objective of this study was to estimate the performance and adaptability parameters of simple corn hybrids in the northern region of Tamaulipas, Mexico. This will provide farmers with better alternatives to select the material of their interest, thereby taking advantage of the hybrid's high potential and achieving higher income.

MATERIALS AND METHODS

Base genetic material: As female parents, 217 white-grain corn lines were used, and the male parent was line T-42. These lines were developed within the Corn Breeding Program of the National Institute of Forestry, Agriculture, and Livestock Research (INIFAP) at the Río Bravo Experimental Station (CERIB), Tamaulipas.

Formation of Single or Hybrid Crosses: In an isolated plot, the 217 corn lines and an elite line (T-42) with good combining ability were planted. The planting was done in a 4:2 ratio, *i.e.*, 4 female rows and 2 male rows. Each line was sown in a single 5.0 m-long row, with a row spacing of 0.80 m. The hybrids were formed during the spring-summer (S-S) 2022 cropping season at INIFAP-CERIB. At flowering, the female lines were detasseled manually by field personnel, leaving the male line intact. Out of the 217 expected combinations, 43 single hybrids were successfully obtained.

Location and Evaluation of the Hybrids: The evaluation was carried out in two environments. The first was at a cooperating farmer's field in the municipality of Díaz Ordaz, Tamaulipas, located at 26°16' N latitude and 98° 32' W longitude, with an altitude of 50-200 m above sea level. The climate is classified as hot, dry, and extreme (Bshw), with temperatures ranging from 22 to 24 °C and an average annual rainfall of 400-600 mm (INEGI, 2025). The second site was at the Río Bravo Experimental Station, Tamaulipas, located at 25° 23' N latitude and 97° 51' W longitude, with an altitude of 50-500 m above sea level. The climate is classified as very hot, semi-dry (Bshw), with temperatures ranging from 20 to 24 °C and annual rainfall of 400-700 mm (INEGI, 2025). A total of 49 genotypes were evaluated, of which 44 were white-grain single or hybrid corn lines from the CERIB-INIFAP Corn Breeding Program, and five were commercial hybrids from the region used as checks (Table 1).

Sowing and Management of the Experiment. In the Díaz Ordaz environment, sowing was carried out on February 4, while in the Río Bravo location it was carried out on February 20. Both experiments were conducted under irrigation during the Fall-Winter 2022-2023 cropping season. Agronomic management in both sites followed the recommendations of INIFAP-CERIB (INIFAP, 2017).

Experimental Design and Plot Unit: In both locations, the experiments were established using a 7×7 lattice design with three replications. The experimental plot consisted of a single row 5.0 m in length, with a row spacing of 0.8 m and plant spacing of 0.20 m, resulting in a population density of 62,500 plants ha^{-1}. At harvest, the effective experimental unit consisted of 40 fully competitive plants.

Study Variables: Grain yield (GY) was estimated based on the field weight of each plot, adjusted for shelling percentage, and extrapolated to kg ha^{-1} at 14% moisture content. Plant height and conrcob height (PH and CH) were measured in centimeters (cm), from the base of the stem to the insertion of the flag leaf (PH) and to the insertion of the main Conrcob (CH). For both variables, five representative plants from each plot were sampled to record the average height. Days to anthesis and silking (DA); the number of days required for the plant to exhibit the male inflorescence (tassel; DA-M) and the female inflorescence (silks; DA-F). In both cases, data were recorded visually when 50% of the plants showed dehiscent anthers (DA-M) and receptive silks (DA-F). Grain moisture (GM); a 100 g grain sample was collected, and measurements were taken with a Dickey-John moisture tester, expressed as a percentage. Root and stalk lodging (RL and SL); the number of plants with an inclination angle equal to or greater than 30° from the vertical position of the plant (RL) and the number of plants lodged per plot, considering as lodged those with stalks completely broken below the main conrcob (SL). Both variables were expressed as percentages. Corncob appearance (CA); corncob quality was evaluated based on the set of cobs in each experimental unit, expressed as a percentage. A scoring scale from 1 to 5 was used, where 1=good and 5=poor. Poor coverage (PC); number of ears in the experimental unit with poor husk coverage, expressed as a percentage.

Table 1. White-grain single corn hybrids evaluated for yield and agronomic traits in two environments of Tamaulipas, F-W 2022-2023 season.

Genotype	Genealogy	Genotype	Genealogy
GEN1	P12GB#-298-5×T42	GEN26	P17GB#-303-18×T42
GEN2	P12GB#-298-8×T42	GEN27	P17GB#-303-23×T42
GEN3	P12GB#-298-11×T42	GEN28	P17GB#-303-26×T42
GEN4	P12GB#-298-12×T42	GEN29	P17GB#-303-29×T42
GEN5	P12GB#-298-13×T42	GEN30	P17GB#-303-30×T42
GEN6	P13GB#-299-6×T42	GEN31	P18GB#-304-2×T42
GEN7	P13GB#-299-9×T42	GEN32	P18GB#-304-13×T42
GEN8	P13GB#-299-12×T42	GEN33	P18GB#-304-16×T42
GEN9	P13GB#-299-20×T42	GEN34	P18GB#-304-19×T42
GEN10	P13GB#-299-21×T42	GEN35	P18GB#-304-29×T42
GEN11	P14GB#-300-6×T42	GEN36	P19GB#-305-2×T42
GEN12	P14GB#-300-8×T42	GEN37	P19GB#-305-3×T42
GEN13	P14GB#-300-11×T42	GEN38	P19GB#-305-15×T42
GEN14	P14GB#-300-12×T42	GEN39	P20GB#-306-1×T42
GEN15	P14GB#-300-19×T42	GEN40	P20GB#-306-2×T42
GEN16	P15GB#-301-3×T42	GEN41	P20GB#-306-5×T42
GEN17	P15GB#-301-8×T42	GEN42	P20GB#-306-7×T42
GEN18	P15GB#-301-23×T42	GEN43	P20GB#-306-8×T42
GEN19	P15GB#-301-25×T42	GEN44	P20GB#-306-12×T42
GEN20	P16GB#-302-5×T42	GEN45	H-440*
GEN21	P16GB#-302-11×T42	GEN46	P3051W&
GEN22	P16GB#-302-13×T42	GEN47	NB722&
GEN23	P16GB#-302-21×T42	GEN48	P3057W&
GEN24	P16GB#-302-23×T42	GEN49	AG2525W&
GEN25	P16GB#-302-23×T42		

* = CERIB-INIFAP check; & = Regional check.

Statistical analysis. A combined analysis of variance across locations was performed, and mean comparisons were conducted using Tukey's test ($p \leq 0.05$) for the study variables. The linear additive model for the combined analysis was:

$$y_{ijk} = \mu + A_j + k(j) + C_i + (CA)_{ij} + e_{ijk}$$

To carry out the combined analysis of variance, SAS® software version 9.4 was used (SAS Institute Inc., 2016).

RESULTS AND DISCUSSION

The study revealed significant differences ($p \leq 0.01$) among genotypes for the variables grain yield (GY), grain moisture (GM), days to anthesis (DA-M), days to silking (DA-F), plant height (PH), corncob height (CH), root lodging (RL), corncob appearance (CA), and poor husk coverage (PC). However, for stalk lodging (SL), no significant differences were observed (Table 2). The differences found among the evaluated hybrids indicate the presence of broad genetic diversity, which can be attributed to the fact that the F1 progenies originated from different genetic backgrounds. Therefore, it is recommended that breeders broaden the genetic base in their breeding programs and evaluate hybrid combinations to gain knowledge of their performance across various traits such as yield (Cervantes-Ortiz *et al.*, 2018). Similar studies agree with these findings, reporting significant differences in yield and agronomic traits in their analysis of variance (García-Mendoza *et al.*, 2021; Santiago-López *et al.*, 2023; Martínez *et al.*, 2024).

Regarding environments, significant differences ($p \leq 0.01$) were observed for most variables, except for RL and SL. This indicates that the environments under study differ in soil, temperature, and precipitation, which primarily influenced these two variables. In this regard, Ponce-Encinas *et al.* (2022) noted that environments vary from year to year, even within the same locations or regions; therefore, they recommend testing diverse genotypes, including both experimental and commercial hybrids. Similarly, García *et al.* (2020) reported that the performance of each genotype depends on the environmental conditions present in each study location.

Regarding the genotype per environment interaction (G×E), the variable showing significant differences was grain moisture (GM). Therefore, it can be inferred that there are genotypes with good stability and adaptability across both environments (Table 2). These results contrast with Rodríguez-Ortega *et al.* (2024), who reported in their combined analysis that the evaluated materials differ in each ecological niche due to the conditions of each environment. The G×E interaction is essential for plant breeders, as its main objective is to evaluate different genotypes across two or more environments in order to determine the genetic potential of the materials under study. This information is used to identify the genotypes with the highest likelihood of success in each region (García *et al.*, 2020). In this regard, this study reveals that there are single hybrids suitable for commercial use that could be successful in the northern region of Tamaulipas. The mean yield of the evaluated single hybrids was 7,515.5 kg ha^{-1}, higher than the national production of 3,600.0 kg ha^{-1} (SIAP, 2025).

According to Tukey's test ($p \leq 0.05$), the best white-grain hybrids were those that demonstrated high efficiency in yield and agronomic parameters in the Díaz Ordaz and Río Bravo locations, Tamaulipas, Mexico (Table 3). In this regard, the experimental hybrids performed similarly in yield compared to the commercial checks; however, the genotypes that stood out were GEN 34, GEN 15, GEN 16, and GEN 24, showing not only adaptability across both environments but also a clear advantage over the transnational materials (P3051W, NB722, P3057W, AG2525W), as well as the hybrid developed by CERIB-INIFAP (H-440). In this regard, the difference in yield between the best experimental hybrid (GEN 34) and the best commercial check (AG2525W) was 814.8 kg ha^{-1}. However, when comparing GEN 34 with the CERIB-INIFAP check, the difference was 4,149.6 kg ha^{-1}. These results validate the superiority of the experimental genotypes and support their recommendation for adoption in the northern region of

Table 2. Mean squares and significance from the analysis of variance of 49 white-grain corn hybrids based on yield and agronomic parameters, evaluated in two environments of Tamaulipas, Mexico, F-W 2022-2023.

S.V.	D.F.	GY	GM	DA-M	DA-F	PH
Environment (E)	1	39251414.2**	148.4**	8959.6**	9070.3**	87535.1**
R/E	4	3156137.4	5.6**	3.2	5.7	259.9
Subb./Rep.×E	30	1143400.0	2.2*	1.3	1.7	123.6
Genotypes (G)	48	3470324.6**	8.8**	30.2**	37.3**	264.8**
G×E	42	2225290.1	2.1*	3.1	1.3	121.9
Error		1794609.2	1.3	2.2	3.2	117.9
C.V. (%)		17.8	8.4	2.0	2.3	4.8
Media		7515.5	13.7	73.7	75.2	223.2
S.V.	**D.F.**	**CH**	**RL**	**SL**	**CA**	**PC**
Environment (E)	1	67628.1**	18.1	2.7	1.3**	2102.9**
R/E	4	148.5	202.6**	22.2	0.0	398.9**
Subb./Rep.×E	30	47.6	25.0	19.7	0.0	16.4
Genotype (G)	48	177.6**	48.5	103.8**	0.2**	40.5**
G×E	42	97.5	29.0	32.0	0.1	28.7
Error		67.1	29.1	28.2	0.1	22.2
C.V. (%)		8.8	169.7	108.6	26.0	110.1
Everage		92.5	3.1	4.8	1.3	4.2

*, **: significantly different at $p \leq 0.05$ and 0.01, respectively. S.V: sources of variation, D.F: degrees of freedom, GY: grain yield, GM: grain moisture, DA-M: days to anthesis male flowering, DA-F: days to anthesis female flowering, PH: plant height, CH: corncob height, RL: percentage of root lodging, SL: percentage of stem lodging, CA: corncob appearance, PC: poor coverage, R/E: repetition within environment, Subl/Reps × E: subblocks within repetitions by environment, G×E: genotype by environment interaction, C.V: coefficient of variation in percentage.

Tamaulipas, as higher productivity implies greater profitability for farmers in this region. These results are similar to those reported by Hernández *et al.* (2024), who found an experimental hybrid (LEARB9×UAY113) with a yield of 9,600.0 kg ha^{-1}, which was also competitive with the commercial checks. These findings suggest that the selection and release of experimental hybrids can translate into competitive advantages over commercial materials. However, before recommending a new hybrid, it is advisable to evaluate it across multiple agroecological environments to identify genotypes that excel in yield, adaptation, and stability (Paz *et al.*, 2018; Crossa *et al.*, 2006).

The grain moisture (GM) variable is crucial in hybrids because it directly affects the quality and yield of the harvested grain. In this context, the hybrids with the highest GM content were GEN 27, GEN 42, GEN 34, and GEN 4, with values above 15.0%. However, genotypes GEN 48, GEN 45, GEN 46, GEN 6, and GEN 10 presented less than 12.0% GM (Table 3). The difference in GM is mainly attributed to the diverse environmental conditions (temperature, relative humidity, and precipitation during crop development) and the genetic characteristics of each genotype. Hybrids with lower GM are recommended for regions with high environmental humidity, as they facilitate postharvest handling

Table 3. Means of 49 white-grain corn hybrids based on yield and agronomic parameters, evaluated in two environments of Tamaulipas, Mexico, F-W 2022-2023.

Hybrids	GY	GM	DA-M	DA-F	PH	CH	PAL	PSL	CA	PC
GEN34	9184.0 a	15.3 abc	75.3 a-g	77.0 a-e	226.1 abc	95.0 abc	4.4 a	6.3 a-e	1.0 a	4.0 ab
GEN15	8656.3 a	14.2 a-g	76.5 abc	78.1 abc	225.5 abc	96.6 abc	5.7 a	5.4 a-e	1.3 a	5.9 ab
GEN16	8443.1 a	13.9 a-h	72.0 g-m	74.1 c-i	219.5 abc	86.0 abc	4.6 a	0.0 e	1.5 a	7.0 ab
GEN24	8435.3 a	14.0 a-g	75.3 a-g	76.8 a-f	217.0 abc	95.8 abc	3.0 a	4.2 b-e	1.0 a	1.1 ab
GEN49$^{\&}$	8369.1 a	14.7 a-e	74.1 b-j	75.1 a-i	215.5 abc	85.8 bc	0.0 a	1.5 de	1.4 a	0.1 b
GEN14	8304.0 a	14.8 a-e	73.8 b-k	74.6 b-i	225.3 abc	95.3 abc	0.7 a	12.5 a-d	1.1 a	4.6 ab
GEN11	8239.3 a	14.0 a-g	73.0 d-k	74.0 c-j	215.5 abc	89.3 abc	2.0 a	4.4 b-e	1.0 a	9.2 ab
GEN47$^{\&}$	8219.6 a	12.5 d-j	72.1 f-m	72.8 e-k	223.6 abc	87.5 abc	0.0 a	2.0 de	1.6 a	6.3 ab
GEN32	8212.0 a	14.5 a-e	72.6 e-l	74.3 b-i	228.1 abc	94.0 abc	4.3 a	15.9 ab	1.0 a	5.5 ab
GEN46$^{\&}$	8204.1 ab	11.3 hij	69.0 mn	69.6 kl	236.3 a	81.3 c	0.0 a	2.4 de	1.4 a	0.6 ab
GEN7	8109.3 ab	12.5 d-j	70.5 klm	71.6 ijk	218.5 abc	91.8 abc	1.3 a	0.5 de	1.4 a	5.7 ab
GEN12	8069.1 ab	14.5 a-e	74.5 b-h	76.1 a-h	228.6 abc	98.1 abc	2.2 a	5.2 a-e	1.4 a	11.4 a
GEN5	8035.6 ab	13.1 a-j	76.0 a-e	76.5 a-h	206.5 c	93.5 abc	7.0 a	5.4 a-e	1.1 a	3.7 ab
GEN13	8025.5 ab	13.9 a-h	73.8 b-k	75.0 b-i	219.8 abc	91.1 abc	2.6 a	11.6 a-e	1.2 a	3.1 ab
GEN28	7977.5 ab	13.7 a-i	73.3 b-k	74.8 b-i	226.1 abc	92.3 abc	3.6 a	2.4 de	1.1 a	2.2 ab
GEN3	7935.5 ab	14.7 a-e	76.6 ab	78.5 ab	215.3 abc	97.1 abc	3.6 a	5.6 a-e	1.1 a	7.4 ab
GEN31	7866.0 ab	13.5 a-i	74.0 b-j	75.8 a-i	235.8 a	97.8 abc	2.0 a	2.2 de	1.2 a	4.5 ab
GEN40	7814.0 ab	13.1 a-j	75.3 a-g	76.8 a-g	228.0 abc	105.1 a	0.7 a	1.3 de	1.1 a	4.5 ab
GEN25	7754.6 ab	14.0 a-h	74.6 a-g	76.3 a-h	225.5 abc	94.1 abc	0.7 a	1.5 de	1.2 a	6.5 ab
GEN1	7737.8 ab	14.6 a-e	75.5 a-f	76.6 a-f	212.6 abc	85.6 bc	9.1 a	4.6 b-e	1.2 a	3.0 ab
GEN26	7723.3 ab	14.5 a-e	73.8 b-k	75.0 b-i	224.0 abc	88.3 abc	0.6 a	1.9 de	1.2 a	2.7 ab
GEN10	7616.0 ab	11.7 f-j	70.3 j-m	72.3 h-k	227.0 abc	87.6 abc	1.2 a	4.4 b-e	1.2 a	5.7 ab
GEN30	7593.1 ab	14.2 a-g	74.5 b-h	76.8 a-f	226.0 abc	96.1 abc	3.4 a	3.2 cde	1.6 a	3.4 ab
GEN23	7585.5 ab	13.2 a-j	73.1 c-k	74.6 b-i	222.3 abc	91.0 abc	9.8 a	10.7 a-e	1.1 a	1.9 ab
GEN27	7512.5 ab	15.7 a	75.0 a-g	77.0 a-e	229.8 abc	95.6 abc	0.0 a	1.1 de	1.2 a	1.0 ab
GEN2	7510.6 ab	14.4 a-f	76.1 a-d	77.5 a-d	212.5 abc	93.1 abc	0.7 a	7.4 a-e	1.4 a	2.7 ab
GEN29	7482.8 ab	14.1 a-g	74.3 b-i	76.0 a-h	231.6 abc	95.5 abc	2.4 a	1.2 de	1.3 a	3.0 ab
GEN18	7456.6 ab	14.7 a-e	73.8 b-k	75.5 a-i	224.6 abc	94.1 abc	0.6 a	4.6 a-e	1.2 a	7.7 ab
GEN17	7437.6 ab	12.9 b-j	73.3 b-k	75.1 a-i	224.3 abc	86.0 abc	2.5 a	3.0 cde	1.5 a	4.7 ab
GEN9	7422.1 ab	13.6 a-i	71.1 h-m	72.5 g-k	227.6 abc	87.8 abc	9.1 a	0.7 de	1.5 a	3.1 ab
GEN42	7418.1 ab	15.4 ab	76.1 a-d	78.0 abc	229.3 abc	100.3 abc	2.7 a	3.0 de	1.2 a	2.1 ab
GEN33	7400.0 ab	14.9 a-e	75.1 a-g	76.8 a-f	222.6 abc	92.3 abc	7.4 a	3.7 b-e	1.3 a	2.0 ab
GEN48$^{\&}$	7399.1 ab	10.6 j	69.5 lm	69.8 jkl	220.1 abc	95.3 abc	0.0 a	1.2 de	1.6 a	5.1 ab
GEN22	7218.1 ab	14.8 a-e	74.0 b-j	75.6 a-i	216.5 abc	89.1 abc	3.9 a	1.7 de	1.3 a	6.3 ab
GEN4	7138.5 ab	15.0 a-d	78.0 a	79.3 a	221.8 abc	94.3 abc	12.3 a	5.1 a-e	1.1 a	1.1 ab
GEN44	7028.5 ab	12.9 b-j	73.1 c-k	74.3 b-i	223.6 abc	93.6 abc	3.5 a	7.2 a-e	1.1 a	1.4 ab
GEN19	6964.6 ab	13.1 a-j	73.8 b-k	75.8 a-i	224.5 abc	84.3 bc	0.6 a	2.4 de	1.3 a	6.2 ab
GEN35	6943.3 ab	12.5 d-j	75.1 a-g	77.0 a-e	227.6 abc	95.6 abc	5.0 a	17.1 a	1.3 a	6.7 ab
GEN38	6941.6 ab	13.9 a-h	75.1 a-g	76.8 a-f	223.0 abc	103.0 bc	3.2 a	7.7 a-e	1.2 a	1.9 ab
GEN43	6859.6 ab	13.5 a-i	74.3 b-i	76.6 a-g	224.5 abc	91.0 abc	0.6 a	1.2 de	1.3 a	7.5 ab

Table 3. Continues...

Hybrids	GY	GM	DA-M	DA-F	PH	CH	PAL	PSL	CA	PC
GEN37	6754.0 ab	14.5 a-e	75.3 a-g	77.8 a-d	232.5 ab	90.1 abc	2.9 a	3.8 b-e	1.5 a	2.3 ab
GEN8	6745.0 ab	12.6 c-j	71.0 i-m	72.6 f-k	218.1 abc	95.1 abc	7.5 a	8.9 a-e	1.1 a	4.1 ab
GEN41	6705.6 ab	13.9 a-h	74.5 b-h	76.1 a-h	231.5 abc	98.0 abc	0.0 a	6.1 a-e	1.4 a	4.0 ab
GEN6	6687.3 ab	11.5 g-j	72.6 e-l	73.6 d-k	222.0 abc	93.0 abc	3.0 a	2.5 de	1.7 a	6.0 ab
GEN21	6679.1 ab	14.8 a-e	73.8 b-k	75.5 a-i	217.6 abc	90.3 abc	1.1 a	3.5 b-e	1.1 a	5.4 ab
GEN39	6590.0 ab	13.5 a-i	74.8 a-g	76.6 a-g	226.1 abc	101.1 ab	4.1 a	15.4 abc	1.2 a	2.6 ab
GEN36	6413.5 ab	12.2 e-j	73.6 b-k	75.8 a-i	227.5 abc	90.0 abc	2.5 a	5.9 a-e	1.6 a	1.0 ab
GEN20	6408.8 ab	13.2 a-j	74.0 b-j	76.0 a-h	223.3 abc	84.3 bc	1.3 a	2.1 de	1.5 a	8.9 ab
GEN45*	5034.6 ab	11.1 ij	66.0 n	66.8 l	209.3 bc	83.3 bc	4.7 a	5.8 a-e	1.8 a	1.3 ab
SHD	3141.3	2.7	3.4	4.2	25.4	19.2	12.6	12.4	0.8	11.07

a-n Values with different letters within the same column are significantly different ($P<0.05$).
GY: grain yield, GM: grain moisture, DA-M: days to anthesis male flowering, DA-F: days to anthesis female flowering , PH: plant height, CH: corncob height, RL: percentage of root lodging, SL: percentage of stem lodging, CA: corncob appearance, PC: poor coverage, SHD: significant honest difference. *: CERIB-INIFAP check; &: regional check.

and reduce the need for drying, which in turn decreases costs and improves efficiency at harvest. The varieties and grain moisture (GM) content are key factors that affect the mechanical properties of corn. Therefore, it is essential to understand the influence of these relationships at the time of shelling in order to avoid losses during field harvest (Zhu *et al.*, 2023; Li *et al.*, 2018). In this regard, it is suggested that corn harvest in the field should occur when grain moisture is between 14.0 and 18.0%.

Regarding days to male flowering (DA-M) and female flowering (DA-F), the experimental hybrids exhibited variability in both variables. In this sense, the earliest hybrid was GEN 45, with values of 66.0 DA-M and 66.8 DA-F. On the other hand, GEN 15 and GEN 4 were classified as late materials for both DA-M and DA-F. These results allow the identification of early-, intermediate-, and late-cycle materials (Table 3). The data differ from Canales-Islas *et al.* (2024), who reported maize varieties with male flowering at 81 days and female flowering at 82 days, classifying them as late-cycle, while also identifying early-cycle materials with 73 days for male flowering and 75 days for female flowering. Early-cycle hybrids complete their cycle in a shorter period, allowing less time for grain filling and biomass accumulation, which translates into lower productivity. However, these characteristics are important in regions with early frosts or scarce rainfall, or where there is a need to clear agricultural land for the preparation of the next sowing. Therefore, it is necessary to consider these crosses in a breeding program aimed at earliness (Cervantes-Ortiz *et al.*, 2018). In contrast, late-cycle materials have longer developmental periods, which allow them to take better advantage of the available environmental factors and achieve greater accumulation of assimilates during grain filling. As a result, this is reflected in higher yield values. Nevertheless, it is important to consider the most suitable sowing dates for maize growth, particularly early sowings, since crop development may coincide with rainfall, lower temperatures, and increased relative humidity, which affect both the quantity and quality of grain yield (Odhaib and Hassan, 2024).

The hybrid with the lowest plant height (PH) was GEN 45 with 209.3 cm, while the cross with the greatest height was GEN 46 with 236.3 cm. However, for conrcob height (CH), GEN 46 registered 81.3 cm and GEN 40 reached 105.1 cm (Table 3). A wide diversity was observed among the experimental hybrids, which may have been influenced by the evaluation environments as well as the genetic constitution of each hybrid. Plant height (PH) and conrcob height (CH) are traits closely related to planting density and corn lodging resistance. Therefore, appropriately reducing PH and CH can contribute to increased planting density and yield, as well as improve lodging resistance, which in turn facilitates mechanical harvesting in the field during shelling (Li *et al.*, 2025). In this regard, some authors mention that an ideal plant for harvest should have a plant height ranging from 200 to 240 cm and an ear height between 100 and 150 cm (Conceição dos Santos *et al.*, 2019; Hernández and Esquivel, 2004).

Regarding root lodging (RL), the experimental hybrids performed similarly to the hybrids used as checks. The values for this variable ranged from 0.0 to 9.8%. For stalk lodging (SL), differences were observed among the hybrids, indicating genetic divergence for this trait. The SL range in this study was 0.0 to 17.1%, which impacted the yield of each genotype (Table 3). Lodging in plants can be caused by a combination of factors, including genetic conditions, root and stalk diseases (Ramírez-Diaz *et al.*, 2018), and adverse climatic events such as hail, strong winds, and heavy rainfall (Lindsey *et al.*, 2024). These traits are particularly relevant in the northern region of Tamaulipas, where climatic events are unpredictable. Therefore, when recommending the adoption of new materials for this region, it is advisable to prioritize those that exhibit lower lodging incidence, thus ensuring more stable and profitable production under the agroecological conditions of this region.

For the trait conrcob appearance (CA), no significant differences were observed among the hybrids under study; values ranged from 1.0 to 1.7 (Table 3). This indicates that the experimental crosses were similar compared to the checks used. Regarding poor husk coverage (PC), the hybrid with the lowest value was GEN 49 (0.1%), while the cross with the highest PC was GEN 12 with 11.4%. Similar results were reported by Martínez and De León (1996) in the Veracruz region; however, they did not find differences among the evaluated hybrids. There is a close relationship between these two variables, as having hybrids with poor husk coverage negatively affects ear appearance, compromising grain health and reducing the commercial and agronomic quality of the ear.

CONCLUSIONS

There is wide genetic variability among the evaluated genotypes. This diversity indicates potential for recommending materials with superior agronomic traits and higher yield potential, such as GEN 34, GEN 15, GEN 16, and GEN 24, which demonstrated not only adaptability across both environments but also an advantage over transnational materials. The data generated are essential for guiding selection strategies in a breeding program, facilitating the rapid development of new genotypes.

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