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Results of the First Breeding Cycle Using Maize Accessions from CIMMYT, Mexico

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Abstract

Context: Obtaining germplasm that expresses higher levels of yield, quality, and stress tolerance requires the development of improved maize varieties and hybrids. To this end, preliminary characterization and evaluation may yield useful results, making it necessary to identify the group of individuals that could serve as progenitors of the enhanced generation.
Aim: To evaluate the performance of 21 maize accessions from CIMMYT, Mexico, under the edaphoclimatic conditions of the municipality of Vertientes, Cuba.
Methods: A randomized block design with three replications was used, and the agronomic traits of 24 maize accessions were evaluated. The following traits were recorded: plant and ear height, male and female flowering, biological cycle, ear length, number of rows per ear, 1000-grain weight (g), and grain yield ($t \cdot ha^{-1}$).
Results: The vegetative traits—plant height and ear height—proved to be directly proportional, characterized by a short stature. The entries exhibited an early growth cycle, and male flowering occurred approximately ±1.22 days before female flowering.
Conclusions: The entries that exhibited the best agronomic traits were numbers 14, 19, 18, 15, and 10, with an average grain yield of 4.39 $t \cdot ha^{-1}$, respectively. Seeds were obtained from 19 entries for the next breeding cycle. Mass selection was applied in the first generation of the F1, enabling the continuation of the next selection cycle.

Keywords: *maize accessions, morpho-agronomic traits, breeding.*

Introduction

Maize (Zea mays L.) forms the foundation of food and nutritional security (SAN, in Spanish) for the Mesoamerican population, accounting for 61% of total caloric intake and serving as a significant source of protein (Poole et al., 2020).

It is the second most economically important cereal after rice in Cuba and is highly preferred by the population for consumption. Maize is cultivated throughout the island, covering an area of 150,000 hectares, with the eastern provinces standing out for having the largest planted surface (Hernández, 2022).

The same author reports that in 2020, 130,000 hectares of maize were harvested in Cuba, yielding 250,000 tons and an average grain yield of 2.22 $t \cdot ha^{-1}$. Maize with yellow kernels—either flint or dent types—is primarily cultivated for human consumption as fresh ears and for animal feed in its dry grain form.

Despite the crop’s importance and the advances in genetic improvement over recent decades, low yields remain the main challenge for small-scale farmers in the region. To address future challenges associated with climate change and the rising demand for food driven by population growth, it is imperative to implement strategies that promote the sustainable production of this crop, enhance its contributions to food and nutritional security, and reduce the food vulnerability of the regional population (Prasanna et al., 2021).

Hybrid maize was one of the earliest successful applications of genetic theory in food production. The foundation of commercial hybrid development lies in inbred lines with good combining ability; however, the success in obtaining outstanding lines depends on the level of genetic variability present in the segregating population and on the gene frequency of alleles of interest (Borroel et al., 2018).

The use of hybrids may be a decisive factor in maize production in Cuba, as the limited availability of improved germplasm often leads to reliance on creole genotypes with undesirable agronomic traits and low yield potential (Hernández et al., 2018; Ruiz et al., 2022a).

To maintain, conserve, and harness the genetic potential represented by maize landraces and their wild relatives, collections have been established and deposited in various international germplasm banks, such as the one at the International Maize and Wheat Improvement Center (CIMMYT) (Chassaigne, 2022).

The evaluation and characterization of foreign germplasm collections is a fundamental step in genetic improvement programs; the exchange of germplasm among research institutions greatly aids in refining and organizing accessions, and above all, in identifying valuable genotypes for use in breeding programs. Therefore, it is vital to have available information on each material regarding qualitative and quantitative traits of current or future importance (Rosales & Sánchez, 2022).

Maize in Cuba is one of the most important commodities for both human and animal consumption, making it essential to study the plant genetic resources available in the Caribbean region in order to strengthen the country's germplasm bank with new accessions. Building on the Cuba–Mexico collaboration with CIMMYT, which holds a larger quantity of advanced genetic material geared toward hybrid development and improved varieties, these resources are being used by regional programs to boost agricultural yields (Ruiz et al., 2022b).

The purpose of developing S1 lines from segregating populations is to exploit the effect of transgressive inheritance in agronomic traits, which would allow the selection of lines that exhibit greater phenotypic expression than their best parent, thereby enabling the identification of outstanding inbred lines (Rebolloza et al., 2020).

The use of commercial hybrids, native varieties, and open-pollinated foreign-origin varieties can serve as a genetic source for obtaining pure lines, which may be used in breeding programs. Therefore, the objective of this research is to evaluate the performance of 21 maize accessions from CIMMYT Mexico under the edaphoclimatic conditions of the municipality of Vertientes, Camaguey province, Cuba

Materials and methods

The experimental trial was conducted at the Vertientes Scientific-Technological Base Unit, located in Camagüey Province at coordinates 21° 5′ 23″ North latitude and 78° 10′ 21″ West longitude, along Sexto Anillo Highway at kilometer 22½, at an elevation of 48 meters above sea level, on a gleyed dark plastic soil with a pH of 6.4 and an organic matter content of 2.67%, according to site cartographic sheets and corroborated by Hernández et al. (2015).

A randomized block design with three replications was used, covering a total planting area of 419.8 m², where the S_0 generation of each accession was sown in two rows of 5 meters in length per entry. The planting distance was 0.70 × 0.20 meters. At flowering, self-pollination was performed on 720 F_1 plants, selecting those from each plot with the best agronomic and health traits, and applying a 10% selection pressure.

The morpho-agronomic traits of 21 maize accessions—10 triple hybrids and 11 varieties from CIMMYT—were evaluated, using the open-pollinated varieties (OPVs) MAIG-5461, MAIG-5462, and Tuson as controls (see Annex 1).

Planting was carried out during the wet season (April 2020). The agronomic management of the experiment was carried out in accordance with the recommendations outlined in the Technical Guide for Maize Cultivation (Cantillo et al., 2020).

Evaluations

The following traits were recorded: plant and ear height, male and female flowering, biological cycle, ear length, number of rows per ear, weight of 1,000 grains (g), and grain yield per hectare in $t \cdot ha^{-1}$ (IBPGR, 1991).

Statistical analysis

For the variables ear length, number of rows, weight of 1,000 grains, and grain yield, analysis of variance and mean comparison were performed using Duncan's test ($p \leq 0.05$). Statistical analysis of the data was performed using the SPSS Statistical Package, version 24.0.

Results and discussion

Statistically significant differences were found among the accessions subjected to the first improvement cycle in several of the evaluated traits: plant height, ear height, biological cycle, and days to male and female flowering (Table 1).

The recorded average for the variable plant height was 161.4 cm, with a minimum value of 111.6 cm corresponding to entry number 22, and a maximum value of 197.0 cm belonging to entry number 14, one of the controls; the coefficient of variation was 8.59%, indicating significant differences across all entries and control varieties. Regarding this trait in the selection process, Vega (1972) and San Vicente (2022) noted that taller plants are more susceptible to lodging caused by wind and rain, resulting in crop losses. The selection of shorter plants has proven effective in terms of yield.

According to Vargas & Castillo (2019), the variable plant height is a varietal trait determined by stem elongation resulting from the accumulation of photosynthates produced in the leaves, which are translocated to the grains; moreover, it is of great interest in relation to mechanized harvesting. Plant height can also be affected by the combined action of four fundamental factors: light, moisture, nutrients, and population density.

Table 1. Functional analysis of five vegetative traits across the 21 entries and three controls

Entry	Plant height (cm)	MZ Height (cm)	Days to flowering (days)		Cycle (days)
			Male	Female	
1	159.9_{d}	77.1_{e}	51_{b}	52_{b}	113_{b}
2	164.9_{c}	87.6_{c}	50_{b}	51_{b}	117_{ab}
3	170.4_{b}	84.3_{d}	51_{b}	53_{b}	118_{a}
4	167.6_{c}	91.0_{c}	51_{b}	52_{b}	116_{ab}
5	176.5_{b}	$95.3b_{c}$	50_{b}	51_{b}	118_{a}
6	170.2_{b}	$97.2b_{c}$	51_{b}	52_{b}	119_{a}
7	171.6_{b}	103.9_{b}	51_{b}	52_{b}	120_{a}
8	171.7_{b}	93.6_{bc}	52_{a}	53_{b}	116_{ab}
9	125.0_{f}	71.0_{e}	50_{b}	51_{b}	119_{a}
10	175.0_{b}	89.0_{c}	49_{b}	51_{b}	116_{ab}
11	169.8_{bc}	99.3_{bc}	51_{b}	52_{b}	121_{a}
12	153.2_{d}	81.8_{d}	49_{b}	50_{c}	120_{a}
13	197.0_{a}	124.0_{a}	51_{b}	53_{b}	123_{a}
14	158.0_{d}	85.7_{d}	51_{b}	52_{b}	110_{c}
15	168.4_{c}	98.7_{bc}	50_{b}	51_{b}	114_{b}
16	158.1_{d}	84.5_{d}	50_{b}	52_{b}	119_{a}
17	158.3_{d}	83.4_{d}	50_{b}	52_{b}	118_{a}
18	175.3_{b}	102.2_{b}	50_{b}	51_{b}	119_{a}
19	172.9_{b}	91.6_{c}	50_{b}	51_{b}	121_{a}
20	146.1_{e}	72.0_{e}	54_{a}	55_{a}	120_{a}
21	111.6_{g}	53.4_{f}	54_{a}	55_{a}	119_{a}
22	150.8_{d}	84.8_{d}	55_{a}	56_{a}	117_{ab}
23	157.4_{d}	88.6_{c}	52_{a}	54_{a}	120_{a}
24	143.2_{e}	78.9_{de}	53_{a}	54_{a}	111_{c}
Mean	161.4	88.29	51.04	52.26	118
VC%	10.92	15.36	3.096	2.897	2.66
SE	7.218	2.249	0.318	0.309	0.654

*Different scripts within the same column indicate statistically significant differences ($p \leq 0.05$).

The average height measured from the base of the plant to the node of ear insertion was 88.29 cm (Table 1), with a minimum value of 53.4 cm observed in entry number 22 and a maximum value of 124.0 cm corresponding to entry number 14 (control), and a coefficient of variation of 15.36%. The results show consistency between plant height and ear height; in this regard, Gutiérrez et al. (2004) concluded that there is a strong phenotypic association between plant height and ear height; in other words, these variables are directly proportional, which supports the results obtained in this trial.

De la Cruz (2007) considered it advisable to use low and medium-stature materials, as these tolerate high plant densities per hectare, without neglecting the positive relationship between plant height and grain yield potential.

Liu et al. (2016) stated that both plant height and ear insertion height are very important agronomic traits in maize genetic improvement, as they influence potential yield. On the other hand, Prasanna et al. (2021) stated that these traits, in addition to being correlated with each other, are also correlated with lodging. Therefore, the use of medium- or low-stature plants is recommended, with an approximate plant height of 233 cm and an ear height of 117 cm.

The average number of days from sowing to the emergence of the tassel and noticeable pollen release was 51.4 days, with a maximum of 55 days observed in entry number 22, which did not differ significantly from entries 8, 20, 21, 23, and 24. These entries outperformed the three controls and the rest of the evaluated entries. A minimum of 49 days was reported for entry number 10. The number of days from sowing until 50% of the plants exhibited exposed stigmas at least two centimeters long ranged from a minimum of 50 days for the control MAIG-5461 to a maximum of 56 days. No statistically significant differences were observed among entries 20, 21, 23, and 24. The average was 52.26 days, as shown in Table 1. These two quantitative variables were shown to be proportional.

The results show a difference of ±1.22 days between both flowering events across all entries and controls, indicating good floral synchrony—an influential factor in production. Authors such as López (1968), Vega (1972), Ayala & Oñate (2007), and Chávez et al. (2022) reported that plant height and ear height are associated with flowering time, with shorter plants being the earliest to flower.

The results obtained differ from those presented by Cao et al. (2017) in a study of hybrids, who reported that they took between 71 and 76 days to reach male and female flowering, respectively.

Ruiz et al. (2022a) in their study confirmed that the materials had an average of 64.8 days, with a range between 62 and 66 days after germination.

In this regard, Rebolloza et al. (2020) demonstrated that the average phenotypic response of the S1 lines in the anthesis–silking interval was five days under drought conditions, while under irrigation the average was two days.

An accession is considered late after 65 days and early between 42 and 45 days, according to Gutiérrez et al. (2020), which reveals that the evaluated accessions exhibited intermediate flowering, making them of great interest in the selection process.

The biological cycle for all entries was relatively short, with an average of 117.5 days after sowing. The earliest cycle was observed in entry number 15, with 110 days, which differed statistically from the controls and the rest of the entries. The longest cycle was recorded in entry number 12 (control), with 123 days.

The recorded values for the ear length variable ranged from 13.5 cm in entry number 2 (minimum) to 17.1 cm in entry number 19 (maximum), surpassing the controls and other entries. The average was 15.05 cm, with a coefficient of variation of 6.155%. (Table 2). Guacho (2014) concluded that plant height does not significantly influence ear length. Ayala & Oñate (2007) and Ortigoza et al. (2019) reported that ear length is a trait correlated with yield; however, it is also a low-heritability attribute (10–30%), meaning it is highly influenced by environmental factors. However, Vera (2024) explains that physical factors such as sowing depth and seed health influence this variable and may cause significant differences among accessions.

Table 2. Functional Analysis of Quantitative Traits of Five Agronomic Characteristics in Maize from 21 Accessions and Three Controls

Entry	Ear Length (cm)	Number of rows	Number of kernels/MZ	Total of 1000 kernels (g)	Yield per $t.ha^{-1}$
1	15.4_{a}	16.2_{a}	32_{b}	305_{bc}	3.54_{b}
2	13.5_{bc}	15.4_{a}	29_{bc}	309_{bc}	2.27_{c}
3	15.8_{a}	15.6_{a}	30_{bc}	391_{ab}	2.36_{c}
4	13.8_{bc}	16.2_{a}	34_{ab}	315_{b}	2.63_{c}
5	16.3_{a}	13.6_{b}	35_{ab}	348_{b}	2.3_{c}
6	14.9_{b}	13.6_{b}	34_{ab}	329_{b}	3.15_{b}
7	14.6_{b}	14.6_{b}	35_{ab}	309_{bc}	2.58_{c}
8	14.2_{b}	13.4_{b}	31_{bc}	250_{c}	2.42_{c}
9	14.1_{b}	14.0_{b}	30_{bc}	249_{c}	2.07_{c}
10	15.9_{a}	13.8_{b}	32_{b}	330_{b}	4.11_{a}
11	14.2_{b}	14.2_{b}	33_{b}	301.5_{bc}	4.54_{a}
12	14.8_{b}	15.2_{a}	31_{bc}	320_{b}	3.69_{b}
13	15.6_{ab}	13.9_{b}	33_{bc}	429_{a}	2.60_{c}
14	14.6_{b}	16.0_{a}	34_{b}	330_{b}	4.61_{a}
15	15.9_{a}	14.0_{b}	33_{bc}	321_{b}	4.15_{a}
16	15.0_{ab}	14.0_{b}	36_{ab}	358_{b}	3.68_{b}
17	15.7_{ab}	14.0_{b}	36_{ab}	340_{b}	3.46_{b}
18	16.0_{a}	12.0_{c}	32_{bc}	382_{ab}	4.52_{a}
19	17.1_{a}	16.0_{a}	39_{a}	376.6_{ab}	4.57_{a}
20	13.8_{bc}	14.0_{b}	30_{c}	305_{bc}	3.42_{b}
21	14.0_{b}	12.0_{c}	33_{b}	328.5_{b}	2.29_{c}
22	15.0_{ab}	14.0_{b}	31_{c}	308.5_{bc}	2.18_{c}
23	15.0_{ab}	16.0_{a}	32_{c}	283.5_{cd}	2.44_{c}
24	15.9_{a}	14.0_{b}	30_{c}	278_{c}	2,12c
Mean	15.05	14.4	32.71	324.86	3.15
VC%	6.155	8.29	7.295	12.94	14.46
SE	0.193	0.24	0.487	8.579	0.184

*Different scripts within the same column indicate significant differences ($p \leq 0.05$).

The number of rows per ear was recorded, with an average of 14.4 grain rows per ear. The maximum was 16.2 rows, observed in entries 1, 2, 3, 4, and 10, respectively, while the minimum was 13.4 rows, corresponding to entry 8. The number of grain rows per ear is strongly controlled by genotype and is minimally affected by variations in climatic conditions (Callava, 2020).

The trait "number of grains per ear" showed an average value of 32.71 grains, ranging from 29 grains (entry 2) to 39 grains (entry 19), and a coefficient of variation of 7.295%, as shown in Table 2. It can therefore be deduced that the number of grains is directly related to ear length, with the longest ears (entry 19), measuring 17.1 cm, containing 39 grains per ear.

The average value for the 1,000-grain weight component was 312.5 g, with a maximum of 391 g (entry 3) and a minimum of 249 g, corresponding to entry 9. The coefficient of variation was 12.86% (Table 2). These data were collected when the ears reached an average moisture content of 14.35%.

Table 2 shows the average yield obtained in the performance trial was 3.09 $t{\cdot}ha^{-1}$. The highest yield was 4.61 $t{\cdot}ha^{-1}$ (entry 14), which did not differ statistically from entries 19, 11 (control), 18, 15, and 10, respectively. However, it did differ statistically from controls 12 and 13 and the rest of the entries. The lowest yield was recorded in entry 9, with 2.07 $t{\cdot}ha^{-1}$. These results indicate a contribution among the variables ear length, number of rows, number of grains, and 1,000-grain weight, consistent with the findings reported by Borroel et al. (2018).

Yield is a complex trait, and its expression depends on the functioning and interaction of various physiological components, whose limits vary according to the genotype and the environment in which it develops (De la Cruz, 2007; Pacheco et al., 2017; Clemente et al., 2022).

It was confirmed that the yields of the maize accessions were low. According to Jurado (2022), the causes of low maize yield may be influenced by the climate in which it was grown, the short day length, the short vegetative cycle of the crop, and abiotic stress typical of tropical regions. Droughts and low soil fertility are also cited as limiting factors in crop yields.

The variability present in the available germplasm is a fundamental requirement for identifying genotypes with specific traits. Traditionally, genetic diversity was estimated based on agro-morphological traits, with the limitation posed by the interaction of their expression with the environment (Rossi et al., 2019).

In the selection process of the lines obtained for the next cycle, new materials are available from entries 1, 6, 10, 11, 12, 14, 15, 16, 17, 18, 19, and 20, which stood out in terms of yield, uniformity, plant height, ear height, days to male and female flowering, and certain agronomic traits such as number of rows, ear length, and ear diameter.

Díaz et al. (2021) indicated that depending on the size of the base population, the evaluation of progenies, and the recombination method used, these variables influence the response to selection. Therefore, to avoid genetic drift, they suggest using 30 families if five or more selection cycles are to be carried out. They also mention that genetic drift is stronger when fewer than 10 families are used in recombination. In this study, 80 families were selected in the first cycle, which ensures the preservation of genetic variability.

The results obtained in this study become a valuable tool for advancing the genetic improvement processes of the populations from which the evaluated lines were derived. However, this should be complemented with genetic diversity studies using molecular methods in order to gain deeper insight into the genetic distances among different population groups, aimed at obtaining lines for hybridization programs. This collection of 21 maize accessions from CIMMYT represents a valuable resource for driving future genetic gains in maize breeding programs being developed in Cuba.

Conclusions

Outstanding S1 lines were obtained, with some traits of interest for the next selection cycle.

The best yield results were obtained from entries 10, 14, 15, 18, and 19, while entry 9 showed the lowest yield and was discarded for the next selection cycle.

Recommendations

Continue with the selection cycles to gradually enhance the desirable traits of these materials, with the aim of obtaining inbred lines for the development of new hybrids and improved varieties adapted to our agroclimatic conditions.

Author contribution statement

Genry Hernández Carrillo: Research conception and development , experimental design, data analysis, article writing, and final review.

Ibrahim Pérez Cantillo: Research development and result analysis, final review.

Idania L. Yero Pino: Research development and result analysis, final review.

Conflict of interest statement

The authors state there are no conflicts of interest whatsoever.

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Appendix

Appendix I Genetic material used in the study, its origin, and grain color

Entry	Accessions	Material	Origin	Kernel color
1	(CLRCY017/CL02450)// CML451	Triple hybrid	CIMMYT	White
2	(CLRCY016/CL02450)// L02720	Triple hybrid	CIMMYT	White
3	(CLRCY017/CL02450)// CLYN205	Triple hybrid	CIMMYT	White
4	(CLRCY017/CL02450)// CLYN214	Triple hybrid	CIMMYT	Yellow
5	(CLRCY040/CLYN206)// CLRCY017	Triple hybrid	CIMMYT	Yellow
6	(CLRCY017/CL02450)// CLRCY040	Triple hybrid	CIMMYT	Yellow
7	(CL02720/CML451)// CLRCY016	Triple hybrid	CIMMYT	Yellow
8	(CL02450/CLRCY041)// CLYN214	Triple hybrid	CIMMYT	Yellow
9	(CL02450/CLRCY041)// CML451	Triple hybrid	CIMMYT	Yellow
10	(CLRCY044/CLRCY039)// CL02450	Triple hybrid	CIMMYT	Yellow
11	MAIG-5462 (Control)	VPL	IIG	Yellow
12	MAIG-5462 (Control)	VPL	IIG	Yellow
13	Tuson (Control)	VPL	IIG	Yellow
14	S11TLWNHGAB03	VPL	CIMMYT	Yellow
15	S11TLWNHGAB05	VPL	CIMMYT	Yellow
16	S11TLWNHGAB06	VPL	CIMMYT	Yellow
17	S11TLWNHGAB08	VPL	CIMMYT	Yellow
18	S11TLYNHGAB01	VPL	CIMMYT	Yellow
19	S11TLYNHGAB02	VPL	CIMMYT	Yellow
20	S11TLYNHGAB03	VPL	CIMMYT	Yellow
21	S11TLYNHGAB04	VPL	CIMMYT	Yellow
22	S03TLW3HGB	VPL	CIMMYT	Yellow
23	S06TLWQHGAB02	VPL	CIMMYT	Yellow
24	S07TLYNHGAB01	VPL	CIMMYT	Yellow