EVALUATION OF HYBRIDS FROM SIMPLE CROSSES USING MAIZE ELITE LANDRACES WITH FORAGE OUTSTANDING CHARACTERISTICS FOR A MEXICAN ARID LAND

[EVALUACIÓN DE HÍBRIDOS DE CRUZAS SIMPLES USANDO LÍNEAS ÉLITE DE MAÍZ CON CARACTERÍSTICAS FORRAJERAS SOBRESALIENTES PARA UNA REGIÓN ÁRIDA DE MÉXICO]

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SUMMARY

The Comarca Lagunera region is the most important area of maize forage in México. In this region; which is shared by the Mexican States of Coahuila and Durango, are used a great amount of hybrids and varieties of maize imported from other countries. Generally, these genotypes are not completely adapted to the soil and/or climatic conditions of the region. These antecedents lead scientists to pursuit for genotypes with the best adaptation to such conditions. The present investigation was carried out with the aim to find the best hybrids from the crosses of ten self-pollinating landraces following a diallel mating design. The landraces were obtained from different institutions: a) the International Maize and Wheat Improvement Center (CIMMYT), b) the "Antonio Narro" Agrarian Autonomist University (UAAAN), and c) the National Institute of Agriculture, Forestry and Livestock Research (INIFAP). The following variables were evaluated from the hybrids: whole plant fresh matter yield (FMY), whole plant dry matter (DMY), fresh fruit yield (FFY) fresh stem yield (FSY), and fresh foliar yield (FLY). All variables reported as t ha⁻¹. The Griffing statistical analysis was used to determine the general combining ability (GCA), and the specific combining ability (SCA). The highest values of GCA were obtained for the landraces M7, M8, and M9. The hybrids with highest SCA were: M5xM7, M2xM7, M6x10, M4xM8, M5xM8, M8xM10, M2xM5, M1xM10 and M6xM9. Two of these hybrids (M5xM7 and M2xM7) also showed the highest values for FMY and DMY. In conclusion, there is enough variability on FMY and DMY to believe on the possibility to find the most appropriate hybrid for the targeted region, and also to extend the breeding program to other arid lands in México

Keywords: breeding; selection; genetic expression; heritability; hybrid.

RESUMEN

La Comarca Lagunera es la zona productora de maíz forrajero más importante en México. En esta región; la cual implica un área compartida por los estados mexicanos de Coahuila y Durango, son utilizados una importante cantidad de híbridos y genotipos de maíz importados de otros países. En lo general, esos genotipos no están ampliamente adaptados a las condiciones de suelo y/o clima de esta localidad. Esos antecedentes guían a los científicos a buscar los genotipos que presenten la mejor adaptación a tales condiciones. El presente trabajo de investigación fue realizado con la finalidad de encontrar los mejores híbridos provenientes de la cruza mediante un diseño dialélico de diez líneas autógamas. Las líneas fueron obtenidas de diferentes instituciones: a) el Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), b) la Universidad Autónoma Agraria Antonio Narro (UAAAN), y c) el Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Las variables evaluadas en los híbridos fueron las siguientes: rendimiento de materia fresca total (FMY), rendimiento de materia seca (DMY), producción total de elote (FFY), producción total de tallo (FSY), y producción total de hoja (FLY). Todas

las variables fueron determinadas en t ha^{-1}. El análisis estadístico de Griffing fue utilizado para calcular los efectos de aptitud combinatoria general (GCA) y aptitud combinatoria específica (SCA). Los valores más altos de GCA fueron obtenidos por las líneas P7, P8 y P9, para todas las variables estudiadas Los híbridos con mejores rendimientos tanto en FMY, como de DMY fueron: M5xM7, M7xM8, M2xM7, M7xM9, M9xM10, M4xM8 y M8xM9. Las cruzas con mayor SCA para FMY fueron: M5xM7, M2xM7, M6x10, M4xM8, M5xM8, M8xM10,

M2xM5, M1xM10 y M6xM9. De estas cruzas, los híbridos provenientes de M5xM7 y M2xM7 coinciden con los mayores valores de rendimiento, tanto en fresco (FMY) como en seco (DMY). Se concluye que existe suficiente variabilidad en FMY y DMY para creer en la posibilidad de encontrar el hibrido más apropiado para la región de estudio a otras zonas áridas de México.

Palabras clave: mejoramiento vegetal; selección; expresión genética; heredabilidad; hibrido.

INTRODUCTION

Maize (*Zea mays* L.) is the most widely grown cereal in the world. It is also the leading world cereal in terms of productivity (Malik *et al.*, 2005). Maize silage is a high-quality forage crop used in many areas of the world, which help dairy and cattle farmers to maintain a relatively constant forage supply during the year. It is used in mass due to its high yield, energy and digestibility (Lopez *et al.*, 2009).This species grown for forage is one of the main crops in the Comarca Lagunera region. This region is located in the North of Mexico under arid conditions. In this region are grown almost 30,000 ha year^{-1} of this crop (SAGARPA-SIAP, 2007). Approximately, the 90% of such a surface is sowed with commercial hybrids imported from other countries; which are not well adapted to the local soil and/or climatic conditions (Najera *et al.*, 2010). That situation should not be acceptable, because the genetic variation is narrowly related to the environmental conditions of production, as well as to the given uses to this crop (Hernández and Esquivel, 2004).

The knowledge of the morphologic and genetic variation, and also its relationship with the environment determine the strategies of conservation and adequate use of the genetic diversity of maize (Najera *et al.*, 2010). The genetic variation allows integrating all kind of germplasm, which can be used to improve yield and agronomic characteristics on new varieties or hybrids. Genetic variability has been used to produce hybrids with very specific characteristics, for instance, Hayano-Kanashiro (2009) reported that the genetic variability of maize was exploited to produce locally adapted drought tolerant maize cultivars for the dry tropical areas of Indonesia.

These antecedents lead to scientists to search for maize genotypes well adapted to this region. This aim seems to be reachable regarding that, in México and in other American countries there is a tremendous

genetic diversity in this species, as a result of thousands of years of evolution under domestication and hybridization, which has not been effectively exploited (Lopez *et al.*, 2009). In such context, Peña *et al.* (2004) pointed out that most of the maize hybrids commonly used in México have not been developed in plant breeding programs in order to improve the forage quality of maize, but all of them were developed to improve the quality and quantity of grain. Little has been done in order to improve the forage quality of maize, although it has been reported that dairy livestock yielded more milk, and such milk was of better quality when cows were feed with maize improved for forage production. The most important source of germoplasm is given by both local landraces and elite landraces. Local plant varieties differ from cultivars that have been developed by modern plant breeding in that they have not experienced a deliberate and intensive selection during a formal breeding programme (Zeven, 1998). Local landraces are cultivars grown 'on farm' by farmers who reproduce their seed year after year, and they can be distinguished by specific traits. Landraces constitute variable populations where variation can be seen between and within populations (Bitocchi *et al.*, 2009). Elite landraces populations are part of mature breeding programs developed by prestigious institutions. In the case of maize, the most important institution is the the International Maize and Wheat Improvement Center (CIMMYT), which works widely around the world. The objective of the present study was to evaluate suitable landrace combinations to form hybrids or composites for forage production under the soil and climatic condition of the arid Comarca Lagunera region.

MATERIALS AND METHODS

Ten elite landraces were evaluated, representing differences in agronomic response, geographic origin, maturity, height, and grain type: M1 (L-AN) high-endogamy landrace from local varieties of the municipality of Concepción, Jalisco, México, very early and drought tolerant; M2 (L-AN 447) eight

auto-fecundation landrace, from advanced generations of the hybrid "AN-447" with wide-adaptability characteristics; M3 (L-AN 360 PV) landrace obtained from the population named "Pancho Villa", vigorous and wide leaves; M4 (L-AN 130) from the F_4 of "H-507", crossed with the cultivar "Celaya-2", which comes from the region El Bajío (State of Guanajuato, México); M5 (L-AN 123) obtained in divergent form, from local varieties of Jalisco state; M6 (L-AN 388R) low-height landrace, with wide-succulent leaves generated from the F_3 of the hybrid "AN-388"; M7 (L B-32) identified with the genealogy H-353-245-6-10; M8 (L B-39) coming from the landrace INIFAP-B39; M9 (L B-40) originated from INIFAP-B40; and M10 (CML-319) developed by CIMMYT defined by pedigree RecyW89(Cr.Arg/CIM.ShPINPH)6-3-2-4-B-B. Seeds were supplied by the following institutions: a) CIMMYT, b) the "Antonio Narro" Agrarian Autonomist University (UAAAN), and c) the National Institute of Agriculture, Forestry and Livestock Research (INIFAP). Landraces were crossed following a diallel mating design without reciprocals. Crosses were performed in ten isolation blocks, with a size of 289.80 m^2 (3.00 X 1.40 m) each block. In each isolation block, one population was used as the male and the other nine populations were datasseled and used as females.

The experiment was carried out in the Experimental Field of the UAAAN in Torreón, Coahuila. The work was divided in two stages. The first stage was carried out during the spring-summer season of 2009. 45 direct crosses were done [P(P-1)2^{-1}]. In these crosses were used 10 plants of each landrace to obtain the F_1 seed from each crossing. The F_1 seed from every cross was sowed during the second stage, which was carried out at the summer-autumn season of the same year. The F_1 sowing was done on August 21st. Sowing was done by hand in rows of 3 m length and 0.7 m wide. One seed was put every 5 cm. 30 days after sowing weak plants were retired to left a population of 6 plants m^{-1}, given a total density of 85,000 plants ha^{-1}. The size of each experimental plot was 4.2m^2 (3 X 1.40 m). Two rows were used as protection in order to avoid the edge effect. A drip irrigation system was used for watering soil at a constant field capacity (31.0 % of moisture). Fertilization was done using a formulation to supply 180 and 100 kg ha^{-1} per season of nitrogen and phosphorus, respectively.

The following variables were evaluated from the hybrids: whole plant fresh matter yield (FMY), whole plant dry matter (DMY), fresh fruit yield (FFY) fresh stem yield (FSY), and fresh foliar yield (FLY). All variables reported as t ha^{-1}. Each experimental plot was harvested by hand when the kernel milk line in approximately 50% of the plants reached two-thirds

of the way down the kernels at the central part of the ear (Hunt *et al*. 1989). A representative sample of each plant component was taken, weighed fresh, and dried with dry forced air, then weighed dry to provide an estimate of dry matter percentage.

Statistical analyses were done using the SAS program (SAS Institute, 2004). The GCA analysis was done according to the Method 4 of the diallel effects of Griffing (1956). The values statistically highest of the studied variables were such showing values above the mean plus twice the standard error ($\mu + 2\sigma$). The GCA and SCA effects of every variable were tested by t student, obtaining the value by dividing the value of the parameter by its standard error (Singh & Chaudary, 1985) as follow:

$$GCA = \frac{1}{n+2}\left[\sum(yi+yii)2 - \frac{1}{2}y.....2\right]$$

and

$$SCA = Yij - \frac{1}{n+2}(Yi. + Yii + Y.j + Yjj) + \frac{2}{(n+1)(n+2)}Y.....$$

Where the values of GCA = 1/2 σ^2_A, and the value of SCA = σ^2_D, correspond to the additive (σ^2A), and dominance (σ^2D) variances respectively. The sum of both of them contribute the genetic variance value ($\sigma^2 G = \sigma^2A + \sigma^2D$). Analyses of variance were performed for each variable, using a mixed model where environments and genotype x environment interactions were considered random effects. Data corresponding to landraces and all possible crosses among them (excluding reciprocals) were analysed according to Griffing (1956).

RESULTS AND DISCUSSION

According to the combined analysis of variance, the crosses (hybrids F_1) varied highly significantly (P < 0.01) for FMY, DMY, FSY, and FLY, and significantly (P < 0.05) for FFY (Table 1). Variation for GCA was observed highly significantly (P < 0.01) for all the evaluated variables. In the case of SCA, was observed high significance only for FMY. In this context, knowledge of the genetic variance influencing a metric trait (as yield) is important because it allows the researcher to estimate its relative importance to that of the environment (Elia, 2003). The variation coefficients oscillated between 10.30 and 24.55 %, for FMY and FLY, respectively. In this sense, Argillier *et al*. (1995) pointed out that maize forage breeders must consider the vegetative and reproductive components of the maize plant. Lopez et al. (2009) mentioned that hybrids developed for superior forage production are generally early maturing genotypes not adapted to subtropical areas, consequently, under these climates, exotic germoplasm should be considered as a source of

material for breeding programs devoted to the development of hybrids with good forage production. The mean values for the different variables (Table 2) shows that the most outstanding landraces were such with the code M7, M8, and M9. These landraces showed the highest values for FMY and FSY, while these three landraces plus M2 and M10 showed the highest values for DMY. The highest values of FFY were showed by M7, M8, M9, and M10. This result implicates that variability is high among the studied landraces. Theoretically, this variability should be able to generate adequate forage maize for the targeted region. In this sense, there are reports stating that new crosses from exotic populations have generated suitable genotypes for different regions in the world (Lopez et al., 2009).

Thompson (1968) found that a group of exotic and semi-exotic populations yielded on average 28% more digestible dry matter than adapted hybrids, and Stuber (1986) suggested that some semi-exotic materials might be suitable for silage, given their good grain production and great vegetative development. Bosch *et al*. (1994) showed that some tropical maize populations produced high total digestible dry matter yields in semi-exotic crosses with B73 and MO17 inbred lines. Bertoia (2001) noted that landraces with no history of breeding for grain production generated crosses with good forage potential. Additionally, inbred lines from the North American Corn Belt did not demonstrate potential for enhanced stover yield and quality when compared with inbred lines from Argentine germoplasm (Bertoia *et al*. 2002).

Table 1. Mean squares of the diallel variance analysis for five forage variables from ten elite maize landraces at the Comarca Lagunera region.

Variation source	Freedom degree	Fresh matter yield	Dry matter yield	Fresh fruit yield	Fresh stem yield	Fresh foliar yield
Replications	1	2913.0**	111.1**	215.5*	392.1**	115.8*
Cross	44	407.2**	17.2**	64.2*	104.1**	50.9**
ACG	9	1356.0**	51.4**	172.7**	380.3**	123.2**
ACE	35	163.3*	8.5	36.3	33.0	32.4*
Error	44	96.15	8.1	37.7	27.5	22.5
Total	89					
CV (%)		10.30	14.39	19.79	15.42	24.55
Media		95.13	19.84	31.04	34.01	19.35

*, **, Significant at 0.05 and 0.01 probability levels for an F test, respectively.

Table 2. Characterization of five forage variables of ten elite maize landraces at the Comarca Lagunera region.

Landrace	Fresh matter yield	Dry matter yield	Fresh fruit yield	Fresh stem yield	Fresh foliar yield
M1	85.32	18.76	28.73	29.05	16.77
M2	96.36	20.79*	31.92	34.26	18.62
M3	90.14	18.36	29.24	31.26	18.36
M4	87.50	17.77	27.96	31.77	16.13
M5	91.17	19.33	31.38	32.58	17.74
M6	86.12	17.88	26.13	28.89	17.73
M7	108.12*	21.35*	34.96*	41.36*	22.13
M8	103.74*	22.12*	33.25*	38.96*	23.17*
M9	102.53*	20.91*	34.49*	38.92*	21.52
M10	100.33	21.11*	32.31*	33.07	21.35
SD	8.55	2.01	2.49	2.63	2.95

* Values above $\mu + 2\sigma$ (μ = overall mean, σ = standard deviation).

Significant (P < 0.05) and highly significant (P < 0.01) statistical differences were also found in SCA (Table 3) for M7, M8, and M9. For DMY, only M8 showed significant differences with the highest positive value. M7 showed the solely highest value statistically superior for FFY. It was observed a wide variation on the means for all the variables when comparing the hybrids.

The Table 4 shows the mean values of all the variables for the 15 most outstanding crosses concerning DMY and FMY as the most important forage variables. Regarding DMY, the statistically superior group included 20 hybrids, while for FMY, it was observed a group of seven superior crosses. Generally, the crosses of such group of seven are included at the major group of 20 crosses mentioned previously. This result represents a valuable potential in order to find a genotype adequate for the targeted region and purposes. According to Kutka and Smith (2007), composites are appropriate for use as base populations in breeding programs.

Table 3. General combining aptitude (GCA) effects calculated for forage variables of ten maize elite landraces at Comarca Lagunera region.

Landrace	Fresh matter yield	Dry matter yield	Fresh fruit yield	Fresh stem yield	Fresh foliar yield
M1	-11.0	-1.21	-2.59	-5.58	-2.90
M2	1.38	1.07	0.99	0.27	-0.82
M3	-5.61	-1.66	-2.02	-3.09	-1.12
M4	-8.59	-2.32	-3.46	-2.52	-3.62
M5	-4.45	-0.56	0.38	-1.60	-1.81
M6	-10.1	-2.19	-5.51	-5.76	-1.82
M7	14.61*	1.69	4.40	8.26**	3.13
M8	9.68*	2.56*	2.48	5.56**	4.29*
M9	8.32*	1.20	3.88	5.52**	2.44
M10	5.84	1.43	1.43	-1.05	2.24

*, **, Significant at 0.05 and 0.01 probability levels for an F test, respectively.

Table 4. Multiple mean comparisons of forage variables from the 15 most outstanding crosses (hybrids) among ten elite maize landraces in the Comarca Lagunera region.

Hybrid (F_1)	Fresh matter yield	Dry matter yield	Fresh fruit yield	Fresh stem yield	Fresh foliar yield
M5XM7	125.65*	25.85*	43.05*	43.40	21.95
M7XM8	117.85*	25.70*	38.05*	47.75*	17.35
M2XM8	107.10*	24.65*	32.90*	39.90	21.65
M2XM7	127.05*	24.25*	37.80*	49.00	27.25*
M6XM10	105.35	23.90*	28.70	35.70	21.80
M5XM8	106.75	23.85*	32.80*	47.55*	25.10*
M8XM9	107.45*	22.80*	34.20*	44.10*	22.50*
M7XM9	118.20*	22.70*	40.95*	44.60*	28.65*
M9XM10	115.85*	22.45*	39.55*	39.20	25.20*
M8XM10	107.10	22.30*	30.45	35.70	25.90*
M2XM5	98.35	22.30*	36.05*	33.60	18.45
M1XM10	97.30	22.10*	31.85*	30.80	21.30
M6XM9	101.50	21.35*	29.05	35.00	21.85
M2XM10	98.70	21.10*	31.85*	31.85	19.75
M4XM8	109.20*	20.80*	33.95*	40.60	20.80
SD	8.76	2.35	3.07	4.03	2.16

* Values above $\mu + 2\sigma$ (μ = overall mean, σ = standard deviation).
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Composites are obtained by intercrossing two or more open pollinated varieties with the objective of obtaining a new population with high genetic variability (and a high mean for the traits of interest). Miranda Filho and Chaves (1991) brought the theoretical basis of a procedure for selecting composites based on parameters defined in Gardner and Eberhart (1966) model II for diallel crosses. In a few cases, the genetic variability has been already exploited to produce locally adapted maize cultivars for dry tropical regions of Indonesia, Kenya, Mexico and Colombia (Pingali and Pandey, 2001).

In this context, with changes in agricultural systems, the replacement of landraces with modern, genetically uniform, varieties is considered a menace for the maintenance of the wide diversity that characterizes these populations. Indeed, landraces represent a crucial component of agro-biodiversity; they are usually considered to be adapted to specific environments where the within-population diversity component can be very important for achieving yield stability (Zhu *et al*. 2000).

The specific combining aptitude effects are shown in Table 5. Only the variable FMY showed significant differences for almost all of the 15 most outstanding hybrids. Within this group, the crosses M5xM7, M2xM7, M6xM10, and M4xM8 formed the group statistically superior ($P < 0.01$). Other group formed by M5xM8, M9xM10, M2xM5, M1xM10 y M6xM9 showed also important differences in lower significance ($P < 0.05$). The rest of the variables did not show significant values.

Table 5. Specific combining aptitude (SCA) effects calculated on the 15 most outstanding crosses (hybrids) among ten elite maize landraces in the Comarca Lagunera region.

Hybrid (F_1)	Fresh matter yield	Dry matter yield	Fresh fruit yield	Fresh stem yield	Fresh foliar yield
M5XM7	20.35**	4.87	7.21	2.72	1.27
M7XM8	-1.58	1.59	5.11	2.90	-5.77
M2XM8	0.89	1.17	-1.62	0.03	-1.17
M2XM7	15.91**	1.64	1.35	6.44	5.58**
M6XM10	14.50**	4.82	1.74	8.50	2.02
M5XM8	6.38*	2.00	3.88	4.72	7.86**
M8XM9	-5.69	-0.80	1.78	-1.01	6.00**
M7XM9	0.12	-0.04	1.61	6.79	3.72*
M9XM10	-3.56	-1.54	-4.51	-2.83	0.00
M8XM10	6.54*	-9.02	3.18	0.71	1.15
M2XM5	6.28*	1.95	3.62	0.91	1.73
M1XM10	7.35*	2.03	1.96	3.42	2.60
M6XM9	8.17*	2.50	-0.35	1.22	1.87
M2XM10	-3.66	-1.24	-1.62	-1.38	-1.02
M4XM8	12.97**	0.72	3.88	3.53	0.77

*, **, Significant at 0.05 and 0.01 probability levels for an F test, respectively.

CONCLUSION

It was found an important variability among landraces and crosses. The variation coefficients were acceptable for this type of experiments. It was observed a value of 95 t of fresh matter yield, which is an acceptable value for the region under study. The contribution to the variance among the crosses is attributable to the additive effects (GCA), and not significant to the SCA. The superiority of the GCA for the yield traits as FMY and DMY were approximately six and eight times higher respectively to the values of SCA. There is enough variability on FMY and DMY to believe on the possibility to find the most appropriate hybrid for the targeted region, and also to extend the breeding program to other arid lands in México. Future experiments should include the same variables studied in this paper, and also include variables to analyse the nutrient and digestible quality of the landraces and generated crosses.

Regarding their own productivity, the most outstanding landraces in this work were M8, M7, M10, M9 and M2h. The landraces with the highest GCA values were M7, M8 and M9. The crosses with the highest values for FMY and DMY were M5xM7, M7xM8, M2xM7, M7xM9, M9xM10, M4xM8 AND M8xM9. All of these landraces and crosses should be particularly studied in future investigations.

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