Article

Characterization of the response to drought of segregating lines of corn

Elizabeth Ibarra Sánchez[1]
Antonio Castillo Gutiérrez[2§]
María Eugenia Núñez Valdéz[3]
Ramón Suárez Rodríguez[4]
María Andrade Rodríguez[1]
Francisco Perdomo Roldán[2]

[1]Faculty of Agricultural Sciences-Autonomous University of the State of Morelos. Av. University num. 1001, Col. Chamilpa, Cuernavaca, Morelos. CP. 62209. (Ibarra_lizanz@hotmail.com; maria.andrade@uaem.mx). [2]School of Higher Studies of Xalostoc-UAEM. (fperdomor@yahoo.com.mx). [3]Cellular Dynamics Research Center-UAEM. (eugenia@buzon.uaem.mx). [4]Biotechnology Research Center-UAEM. (rsuarez@uaem.mx).

[§]Corresponding author: antonio.castillo@uaem.mx.

Abstract

Drought stress is one of the main causes of the reduction in maize yield in the tropics, mainly in agriculture that depends on rain, which requires the generation of genotypes with tolerance to drought. The objectives of the research were to quantify the agronomic response of a group of segregating S_2 lines of corn in irrigated and drought environments, as well as to select lines with tolerance to water deficit, based on two indices and the average yield of both environments. The study genotypes were 96 segregating S_2 lines, two control lines and two lines not selected for drought. The lines were evaluated under irrigation and induced drought using a Latice Alpha design with four replications, in Ayala, Morelos, Mexico. 10 morphological variables were measured and drought susceptibility indices (ISS) and tolerance index (IT) were estimated. Based on the grain yield in irrigation (3.14 t ha^{-1}), a reduction of 77.7% of the yield in drought (0.7 t ha^{-1}) was observed. The ISS and IT indices identified the LUM69, LUM82 and LUM30 lines as drought tolerant, only LUM69 showed a competitive yield in both environments. The ISS and IT index as criteria to identify tolerant genotypes did not select the lines with the best grain yield under irrigation conditions, so the average yield through moisture environments should be included in the selection criteria.

Keywords: drought tolerance, susceptibility indices, S_2 lines.

Reception date: May 2020
Acceptance date: July 2020

Introduction

Corn (*Zea mays* L.) is the most important crop in Mexico, so that in 2018 approximately 7.4 million hectares were established, with an average yield of 3.8 t ha^{-1}; where 72% was established in the rainy cycle and the rest in irrigation conditions. In the state of Morelos, about 38 thousand hectares of corn are sown, of which 93% are carried out in conditions of rainfall, with an average grain yield of 4 t ha^{-1} (SIAP-SAGARPA, 2019).

In Mexico, 52% of its agricultural area is classified as arid or semi-arid, which makes it highly susceptible to drought (Salinas *et al*., 1998). The water deficit occurs when the amount of rainfall has been significantly lower than normal, with respect to the annual precipitation rate. On the other hand, the effects of stress due to lack of water are directly related to the intensity and duration of the water deficit, which causes a significant reduction in grain yield (CONAZA, 2010; FAO-SAGARPA, 2012; Esparza, 2014).

Drought is the most important factor limiting corn productivity in regions that depend on rainfall (Srivatava, 2014; Shafiq *et al*., 2015). In Mexico, in the last 14 years, high levels of drought have been reported in the spring-summer agricultural cycle; particularly in 2011, there was a rain deficit during the months of June to September, affecting 213% of the area planted with corn for grain (SMN, 2017; SIAP-SAGARPA, 2017).

The magnitude of the effect of the water deficit on the corn grain yield depends on the intensity, duration, and phenological stage in which it occurs, when drought occurs in the vegetative phase, the plant height and the duration of the leaf area are reduced, which affects the photosynthetic rate; however, the most sensitive period in the corn plant is the period between one week before and two weeks after male flowering (Stone *et al*., 2001; Avendaño *et al*., 2005).

The greatest effect observed is the delay in female flowering, increasing the anthesis-emergence interval of stigmas, which reduces the final grain production (Westgate and Boyer, 1986; Saini and Westgate, 2000). When the drought is prolonged, growth, development and production in the corn plant are affected, as a consequence of the impact on physiological and biochemical processes (Khalili *et al*., 2013).

In the quantification of the effect of drought in cultivated plants, indices have been developed that allow measuring the response of genotypes to water deficit, most of the indices are calculated based on grain yield under irrigated and drought conditions (Fischer and Maurer, 1978; Rosielle and Hamblin, 1981), which makes it necessary to identify agronomic characteristics related to adaptation to limiting humidity conditions, which facilitates the selection of outstanding genotypes in a practical and efficient way.

Conventional plant breeding has developed genotypes with tolerance to drought, through methods that evaluate and select genotypes under limiting and non-limiting humidity conditions, which has allowed the identification of desirable characteristics that facilitate obtaining the highest genetic gain in both humidity conditions (Muñoz, 1980; Fischer *et al*., 1989; Bruce *et al*., 2002).

The most used selection criteria for drought tolerance focus on grain yield and secondary characters that contribute to optimizing the response of plants to water deficit (Badu-Apraku *et al*., 2011), the commonly used secondary characters In the indirect selection for drought tolerance they are, short anthesis-emergence interval of stigmas, low foliar senescence, small spike and erect leaves above the cob (Edmeades *et al*., 1999), because the direct selection for grain yield in humidity-limiting environments it is complicated, due to the low heritability of this character (Ribaut *et al*., 1996).

An efficient method to increase tolerance and stabilize yield in low humidity conditions is the recurrent selection of high-yielding genotypes through moisture-deficient and non-moisture-deficient environments. This method has proven to be effective in corn, however, it is expensive and time consuming, in the population of Tuxpeño Sequía corn obtained through eight selection cycles under water deficit, grain yield increased by 108 kg ha^{-1} per cycle (Bolaños and Edmeades, 1993). While, in another study, it was reported that the recurrent selection of five continuous selection cycles, the grain yield in drought had a genetic gain of 12% per selection cycle (Chapman and Edmeades, 1999).

The formation and identification of segregating inbred lines from the F_2 generation, potentiates the generation of genetic variance due to allelic segregation originated by the crossing of highly contrasting inbred lines in the character of interest (Walsh, 2001). From the cross between the contrasting lines SD34 and SD35 in drought tolerance, 230 F_3 families were derived, detecting phenotypic correlations between grain yield and the anthesis-emergence interval of stigmas (-0.5^{**}), as well as with the number of cobs per plant (0.53^{**}), the relatively high heritabilities in drought in these characteristics, facilitated the indirect selection of high-yield genotypes in drought (Agrama and Moussa, 1996).

The tolerant progenitor line of the present study (Ac7643) was also used as a tolerant progenitor to generate 234 segregating families, which were evaluated in conditions of intermediate and severe drought, as well as in irrigation, the variables of male, female flowering, interval anthesis-emergence of stigmas (ASI) and grain yield showed transgressive segregation in severe drought, the ASI of families showed a range from -4.4 to 9.3 days and in grain yield a 61% reduction in yield was observed in drought; regarding the behavior of Ac7643, a short ASI of -0.2 days in intermediate stress and -0.6 days under severe water stress was reported, with a grain yield of 1 326 kg ha^{-1} in the drought environment (Ribaut *et al*., 1996 and 1997). The behavior of the susceptible progenitor line B39 in environments with contrasting humidity, presented values of the anthesis-emergence of stigma and grain yield interval of 1.9 d and 2.4 t ha^{-1}, respectively; while, in drought the values for the same variables were 9.8 d and 0.4 t ha^{-1} (Castillo, 2004).

One of the purposes of generating segregating populations from the cross between a tolerant and a susceptible line is to generate new genetic variation and have the possibility of detecting transgressive inheritance in the phenotypic expression of characteristics of interest. The objectives of the research were to quantify the agronomic response of a group of segregating S_2 lines of corn in irrigated and drought environments, as well as to select lines with tolerance to water deficit, based on the average yield of both environments.

Materials and methods

The study germplasm consisted of 100 maize genotypes, of which 96 were segregating S_2 lines, the control line T-43 with tolerance to drought, control line Ac7729 susceptible to drought and two S_2 lines, from another segregating population. The S_2 lines come from the crossing of lines Ac7643 (tolerant to drought) and B39 (susceptible to drought). Inbred lines T-43 and B39 were provided by the National Institute for Agricultural and Livestock Forestry Research (INIFAP), while lines Ac7643 and Ac7729 were provided by the International Center for Corn and Wheat Improvement (CIMMYT).

The lines were evaluated in field experiments under irrigation conditions and induced drought; they settled in the experimental field of the Xalostoc School of Higher Studies, of the Autonomous University of the State of Morelos, in the municipality of Ayala, Morelos. The locality is characterized by presenting a warm Sub-humid climate, vertisol-type soil, at an altitude of 1 285 m with a temperature range of 8.4 to 36 °C and an average annual rainfall of 912 mm (INEGI, 2008).

The irrigation environment was established in the rainy cycle corresponding to spring-summer 2016, a period in which there was no limitation of humidity for the crop, registering 1 089 mm of total precipitation during the biological cycle of the crop. Regarding the drought environment, it was established in the autumn-winter 2016-2017 agricultural cycle (where rains do not commonly occur), for humidity management in this environment, it provided a planting irrigation (90 mm), an emergency one (40 mm) 9 days after sowing, subsequently three auxiliary irrigations of 55 mm each, at 12 d intervals, suspending irrigation 45 d after sowing; at 77 d, a light irrigation (30 mm) was supplied applying the irrigation in alternate furrows and from day 94 two irrigations of 30 mm each were provided, to favor the filling of grain, applying a total irrigation sheet of 385 mm .

The experimental design used in both environments was a Latice Alpha (0.1), with four repetitions per entry and per environment; the genotypes were sown in 10 blocks, with 10 experimental units per block. The experimental unit was a row 4 m long, 0.75 m wide, and the distance between plants at 0.2 m. The agronomic management of the field experiments were conducted according to the technical guide of the Experimental Field of Zacatepec, Morelos (Trujillo, 2002). 10 response variables were recorded, male and female flowering (FM-d and FF-d), stigma emergence anthesis interval (ASI-d), variables related to flowering were recorded in the phenological stage VT and R1, height of plant and cob (AP-cm and AM-cm), regarding the heights were measured in the R4 stage, rows per cob (HM-No), cob length (LM-cm), cob diameter (DM-cm), weight of 100 grains (P100G-g) and grain yield (RG-t ha^{-1}), the last variables were determined after commercial maturity.

The data generated by the experiments were subjected to combined analysis of variance through the two evaluation environments (irrigation-drought) for the 10 response variables, later a multiple comparison of means was made using the procedure of least significant difference (α= 0.05) and a linear regression analysis.

In order to quantify the response of lines to drought, the drought susceptibility index (ISS) [Fischer and Maurer, 1978] and the tolerance index (IT) [Rosielle and Hamblin, 1981] were determined. The ISS was estimated by the following equation: ISS = 1-[Ys/Yr]/1 - [Ysm/Yr]. Where: Ys= average yield of the i-th line in the drought environment; Yr= average yield of the i-th line in the irrigation environment; Ysm= average yield of all lines in the drought environment and Yrm= average yield of all lines in the irrigation environment. In the ISS, values less than one indicate relative tolerance to drought in the genotypes.

Regarding IT, it was calculated using the following equation: IT= Y_1-Y_2. Where: Y_1= the grain yield of the line in the irrigation environment, Y_2= the grain yield of the line in the drought environment. Relatively lower values in IT indicate that a genotype is drought tolerant.

The values of both indices were calculated for each genotype and each repetition, which allowed a one-way analysis of variance to be carried out, to later carry out a means comparison test, by means of a $DMS_{(0.05)}$ test. All the statistical analyzes were performed using the Statistical Analysis System software (SAS, 2009).

Results and discussion

The lines in the irrigation environment produced an average grain yield of 3.14 t ha^{-1}, compared to the average of the drought environment of 0.7 t ha^{-1}, which induced a reduction of 77.7% due to drought in combination with high temperatures; this is based on the 1 089 mm of precipitation recorded in the irrigation environment, with temperatures fluctuating from 27.7 to 29.5 °C, while in drought, a total irrigation sheet of 385 mm was applied and temperatures of 28.8 to 33.9 °C, restricting humidity near male flowering.

The combined analysis of variance (Table 1) in the sources of variation of Environments, Lines and the Line x Environment interaction showed highly significant differences ($p\leq 0.01$) for all the variables studied. The statistical differences between environments (irrigation-drought) detected by the combined Anova are explained by the contrast in the humidity conditions to which the genotypes were subjected and by the agricultural evaluation cycles; that is, the environmental conditions such as temperature and relative humidity that prevailed in the spring-summer agricultural cycle fluctuated between 15.7 ºC and 28.3 ºC, 74.7 to 78.4%, respectively.

Meanwhile, in the autumn-winter cycle, the temperature ranged between 13.3 ºC and 32.4 ºC and the relative humidity between 31.3 and 51% (INIFAP, 2017; SMN, 2017). The variation in air temperature and relative humidity between the agricultural evaluation cycles have a direct effect on the degree of phenotypic expression, particularly on morphological variables, therefore, environmental fluctuations have an impact on the agronomic response of the germplasm through from different test sites and environments (Zambrano *et al*., 2017).

Regarding the statistical differences detected between lines, this is attributed to the genetic variation present in the group of lines evaluated, because they are segregating lines from the crossing of two contrasting lines in response to drought, which generated allelic segregation at multiple loci, which was reflected in a wide variation in the agronomic response of the lines. On the other hand, direct selection for grain yield under drought has been considered inefficient due to the low heritability of the character (Ribaut *et al*., 1996), so the selection of tolerant lines is considered more effective, evaluating them in limiting and non-limiting water conditions.

Table 1. Statistical values of morphological characteristics of S_2 lines of corn (*Zea mays* L.) evaluated under drought irrigation in Ayala, Morelos, Mexico.

FV	Amb	Reps/Amb	Bl/Reps Amb	Líneas	L x Amb	Error	CV (%)
GL	1	6	72	99	99	522	
FM d	73594**	9.72**	1.4*	12.99**	5.07**	1.03	1.41
FF d	93723**	18.84**	3.52**	16.94**	8.33**	2.25	2.01
ASI	2.1**	0.01 ns	0.01 ns	0.01**	0.01**	0.01	4.02
AP cm	3674313**	1556.27**	393.81**	1061.67**	471.8**	84.82	5.19
AM cm	1070777**	314.46**	161.06**	834.1**	291.36**	70.28	10.05
HM No.	1682**	14.79**	1.68*	14.19**	4.19**	1.2	8.34
LM cm	1212.54**	5.19 ns	2.44**	7.02**	3.61**	1.82	11.7
DM cm	147.49**	0.66*	0.06 ns	0.32**	0.08**	0.05	6.73
P100G g	8719.53**	13.41*	4.34 ns	32.19**	8.42**	3.36	10.98
RG (t ha^{-1})	1201.86**	1.29*	0.43 ns	2.6**	1.6*	0.4	32.61

FV= source of variation; GL= degrees of freedom; ns= not significant; *= significant at 5%; **= significant at 1%; FM= male flowering; FF= female flowering; ASI= anthesis-emergence interval of stigmata; AP= plant height; AM= cob height; HM= rows per cob; LM= length of cob; DM= cob diameter; P100S= weight of 100 seeds; RG= grain yield; CV= coefficient of variation.

The presence of genotype x environment interaction (L x Amb) in all the variables studied showed that the evaluation environments significantly affected the phenotypic expression of the lines; in general, it was observed that the lines with a relatively high grain yield in the irrigation environment were not the most outstanding in the drought environment. Due to the presence of genotype x environment interaction, the evaluation of genotypes to identify drought tolerant, requires evaluations of grain yield under favorable and unfavorable water conditions (Rosielle and Hamblin, 1981), it is because the genotypes respond differentially to the humidity condition and the degree of intensity of the drought (Golbashy *et al*., 2010).

Considering the grain yield in drought, as a criterion for choosing contrasting lines in response to water stress, Table 2 shows the averages of critical characteristics in the drought and irrigation environments of six lines of high and six lines of low relative yield under drought. The group of outstanding lines in yield in the drought environment, with respect to the irrigation environment, showed a reduction of 65.1% in yield; however, the reduction was greater (90%) for the group of lines with low grain yield in drought. Regarding the days to female flowering (FF), both the lines with the highest and the lowest grain yield in irrigation, were earlier (20 and 24 days respectively) compared to the drought environment.

Table 2. Means of the lines with the highest and lowest grain yield selected based on the yield under drought of the group of segregating lines of corn (*Zea mays* L.).

Line	Drought				Irrigation			
	RG (t ha^{-1})	FF (d)	ASI (d)	AP (cm)	RG (t ha^{-1})	FF (d)	ASI (d)	AP (cm)
LUM69	2.12	84	3	101	2.66	65	2	241
LUM80	1.53	83	3	131	5.59	63	1	273
LUM57	1.23	85	3	123	4.02	66	2	252
LUM137	1.23	82	4	97	3.2	60	2	224
LUM51	1.19	83	3	115	3.71	63	0	229
LUM188	1.15	85	4	130	5.05	65	0	278
Mean	1.41	84	3	116	4.04	64	1	250
LUM144	0.32	85	3	122	2.69	62	2	254
LUM134	0.3	92	7	128	3.93	67	2	271
LUM113	0.29	92	8	104	1.84	65	1	256
LUM29	0.28	87	6	103	2.1	63	2	231
LUM108	0.27	86	4	109	3.21	63	2	243
LUM126	0.17	93	6	101	2.32	67	1	253
Mean	0.27	89	6	111	2.68	65	1	251
$DMS_{(0.05)}$	0.43	2.11	1.9	14.8	1.16	2.08	1	10.5

DMS= minimum significant difference.

For the stigma emergence anthesis interval variable, the group of outstanding lines in the drought environment showed a delay of two days with respect to those of irrigation, while the response in lines of lower yield, the delay was four days. Regarding the height of the plant, the group of outstanding lines showed a reduction in height of 53.6%, with respect to the irrigation environment and the group with the lowest yield revealed a reduction in height of the order of 55.8. These results demonstrate the effect of water availability on the agronomic behavior of genotypes, which supports the idea that evaluations to select drought-tolerant genotypes should be carried out in environments that contrast with humidity (Messina *et al*., 2015).

The analysis of variance of the drought susceptibility indices (ISS) and tolerance index (IT), allowed to determine highly significant differences between genotypes for both indices (Table 3), the variation coefficients for the two indices showed acceptable values of 17.27 and 19.98%, for ISS and IT, respectively. The results obtained in both indices, allows us to infer that the segregating population evaluated in this research has a great genetic variability in grain yield, which is manifested both in irrigated and drought environments; which was reflected in the great variation of values of the ISS and IT indices in the tested genotypes. It was observed that the lines with a higher ISS and IT had a lower grain yield in the drought environment, which means a response of susceptibility to water scarcity, while the lines showing small values in the indices may be classified as drought tolerant (Estrada *et al*., 2016).

Table 3. Mean squares of the one-way analysis of variance for the drought susceptibility indices (ISS) and tolerance index (IT).

FV	GL	ISS	IT
Lines	99	0.103**	0.486**
Error	300	0.027	0.09
CV (%)		17.27	19.98

FV= source of variation; GL= degrees of freedom; **= significant at 1%; CV= coefficient of variation.

The indices of susceptibility (ISS) and tolerance (IT) to drought identified two groups of lines; one classified as tolerant, made up of 13 lines and a second group considered as susceptible, made up of five lines (Table 4). both indices identified the same group of lines; however, the position of the lines was different. The lines classified by the indices as tolerant, presented a reduction in the average grain yield of around 58.6% in the drought environment, while the lines classified as susceptible, showed a greater decrease in grain yield in drought (88.9%), these results are similar to those reported by other studies where the yield losses in the drought environment were around 71.5%, in relation to irrigation (Golbashy *et al*., 2010).

Table 4. Tolerant and susceptible lines selected by the drought susceptibility index (ISS) and the tolerance index (IT), in the segregating population of corn (*Zea mays* L.) evaluated.

Line	ISS	IT	Drought RG (t ha^{-1})	Irrigation RG (t ha^{-1})
			Tolerant lines	
LUM69	0.25	0.54	2.12	2.66
LUM82	0.51	0.5	0.66	1.15
LUM30	0.53	0.46	0.6	1.06
LUM28	0.63	0.98	0.49	1.46
LUM109	0.68	0.87	0.57	1.43
LUM10	0.69	0.83	0.69	1.51
LUM70	0.71	1.1	0.82	1.92
LUM96	0.71	0.92	0.56	1.48
LUM153	0.72	0.95	0.61	1.56
LUM78	0.75	1.44	0.98	2.41
LUM33	0.76	1.01	0.74	3.95
LUM101	0.8	1.03	0.52	1.55
LUM38	0.8	0.88	0.47	1.35
Mean	0.66	0.89	0.76	1.81

Line	ISS	IT	Drought RG (t ha^{-1})	Irrigation RG (t ha^{-1})
			Susceptible lines	
LUM173	1.11	3.85	0.62	4.48
LUM73	1.13	3.8	0.48	4.29
LUM97	1.13	3.4	0.47	3.87
LUM44	1.15	3.29	0.36	3.66
LUM134	1.19	3.63	0.3	3.93
Mean	1.14	3.59	0.45	4.05
$DMS_{(0.05)}$	0.23	1.23	0.43	1.16

DMS= minimum significant difference.

On the other hand, the LUM69 line was identified with the lowest value in the ISS index (0.25), which means that it can be classified as the most drought-tolerant line, even exceeding the tolerance control line tolerant T-43 (0.38), additionally the same line LUM69 showed the highest grain yield in the drought environment (2.12 t ha^{-1}); however, in irrigation it was not one of the highest yielding. Regarding the IT index, the LUM69 line was one of the three lines with the highest tolerance to drought with a value in said index of 0.54 and although it was surpassed by the LUM30 (0.46) and LUM82 (0.50) lines, there was no statistically significant difference between the three lines.

Regarding the group of lines classified as susceptible, the five lines revealed having a value higher than 1.01 in the ISS, a value corresponding to the control susceptible line Ac7729; however, no statistically significant differences were observed between the control line and the group of lines classified as susceptible. A similar behavior was observed in the IT index with the group of lines selected as susceptible, these showed statistically equal values to that of the control line Ac7729 (4.64). Although the ISS and IT indices are an acceptable criterion for breeders to identify genotypes with tolerance to drought, these genotypes do not necessarily present the highest yields in the irrigation environment (Jafari *et al*., 2009).

The above is due to the fact that the yield in irrigation and drought are not determined by the same characteristics of the plant, another cause is that the genotype x environment interaction becomes significant when the level of stress increases, additionally when genotypes are selected in environments not limiting, genetic variability is lost for tolerance to some stress (Bänziger *et al*., 2012).

The relationship between the ISS and IT indices with the grain yield in drought, generated a negative slope (b= -0.23^{**}) between the ISS and the grain yield in drought (Figure 1A); whereas, with the irrigation yield, the slope was positive (b= 0.08^{**}) [Figure 1B]. Regarding the IT index, no relationship was detected with the grain yield in drought (b= 0.61ns) [Figure 1C]; but if a marked positive relationship was observed with the grain yield under irrigation (b= 0.83^{**}) [Figure 1D], a result similar to that found in the ISS, although with a greater fit to the regression line. The LUM69 line identified as tolerant to drought, exceeded in the value of both indices to the tolerant control line (T-43), it was observed in the graphs how said line is separated from the group of tolerant lines.

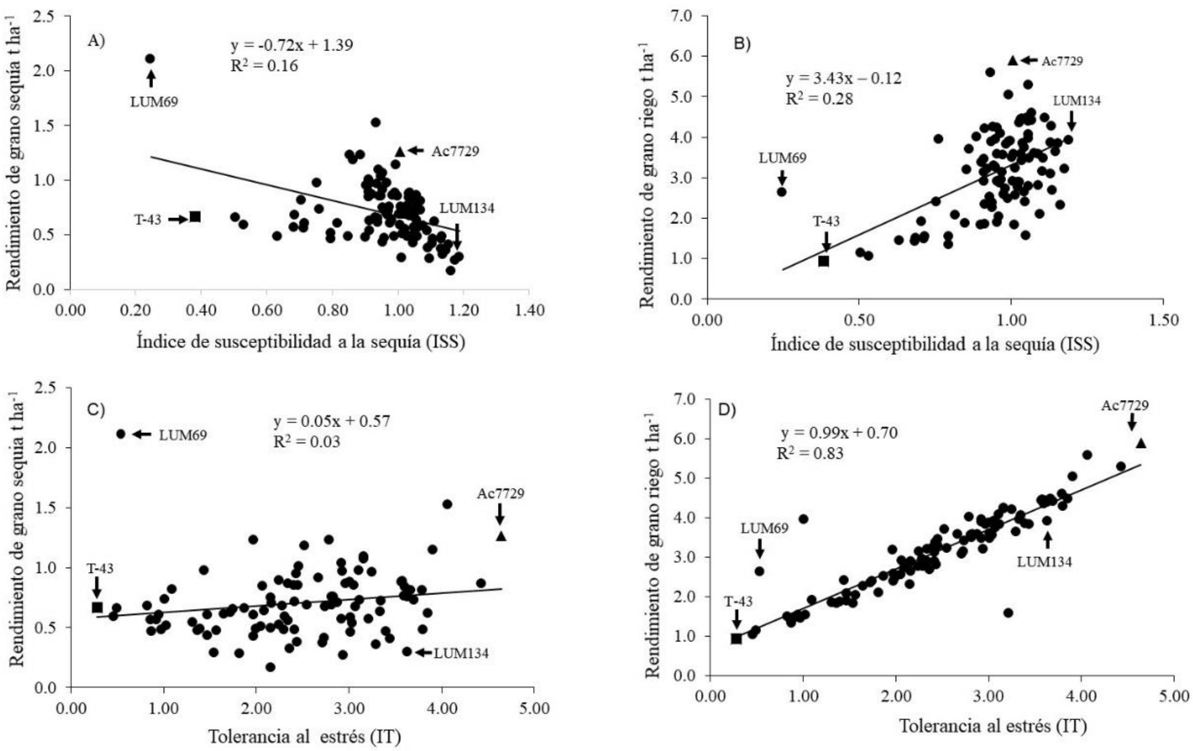

Figure 1. Linear regression between the ISS with the RG under drought (A) and irrigation (B) conditions; and the IT with the yield in drought (C) and in irrigated conditions (D).

The response of the control lines T-43 (tolerant) and Ac7729 (susceptible) was as expected, these lines differ markedly in grain yield under irrigation conditions (5.91 and 0.95 t ha^{-1}, for Ac7729 and T-43, respectively), regarding the reduction in grain yield due to drought, the decrease was very drastic in the Ac7729 line (78.7%), in contrast the decrease in the tolerant control (T-43) was 29.5%, the behavior of the Ac7729 line in this study was very similar to that reported by Ribaut *et al*. (1997).

The wide genetic variation present in the group of segregating lines and observed in the response in the ten characteristics studied in the drought environment; may be one of the main causes of the lack of adjustment to the regression line, particularly with the grain yield in drought, the line LUM69 was identified as the one with the least reduction in yield in drought (20.3%), in contrast to LUM134 had the greatest reduction in grain yield (90.9%). The genotypes that present low values through the ISS and IT indices identify genotypes with good yield under stress, however, they are also those genotypes that present little difference between the irrigation environment and the drought (Mohammadi, 2016).

Based on the fact that the tolerant genotypes identified by the ISS and IT indices are not the most profitable under irrigation conditions, the average was obtained through both evaluation environments (combined RG), with the purpose of identifying which lines integrated extreme contrasting groups in RG. Table 5 shows the two contrasting groups identified. One of the results determined that the mean of the group of lines with the highest combined RG was 69.5% higher than the average of the group of lines with low combined RG.

Table 5. Segregating lines of corn (*Zea mays* L.) with higher and lower grain yields identified through irrigation and drought environments.

Line	Means both environments (t ha^{-1})	Irrigation (t ha^{-1})	Drought (t ha^{-1})
	Higher yield		
LUM80	3.56	5.59	1.53
LUM188	3.1	5.05	1.15
LUM145	3.08	5.29	0.86
LUM184	2.71	4.61	0.81
LUM22	2.68	4.47	0.89
Mean	3.02	5	1.05
	Lower yield		
LUM109	1	1.433	0.57
LUM28	0.97	1.46	0.49
LUM38	0.91	1.345	0.47
LUM82	0.9	1.154	0.66
LUM30	0.83	1.057	0.6
Mean	0.92	1.29	0.56
$DMS_{(0.05)}$	0.62	1.16	0.43

DMS= minimum significant difference.

When analyzing the RG in irrigation between both contrasting groups, it was found that the group of outstanding lines in the combined RG had an average RG in irrigation of 5 t ha^{-1}, surpassing by 74.2% the RG of the lines with low combined RG, while the same comparison, but considering the RG in drought; the combined high RG lines group outperformed the grain yield of the combined low RG lines by 37.1%.

Regarding the group of outstanding lines in combined RG, these identified lines do not coincide with the lines selected as tolerant by the ISS and IT indices. Based on the fact that drought does not occur in every year it should be considered to analyze the average behavior of genotypes through humid environments, to choose the germplasm with the highest tolerance to drought (Rosielle and Hamblin, 1981), due to that the selection of tolerant germplasm based on the ISS and IT indices, identify genotypes that present a lower reduction in RG in drought conditions, but does not guarantee that they are the best in non-limiting humidity conditions (López *et al*., 2008) .

Conclusions

The evaluation of the segregating maize population under irrigated and drought conditions revealed a large amount of genetic variability between lines. The applied intensity of the water deficit was sufficient to induce the genetic expression of the population and identify lines tolerant to this stress factor, as well as producing a 77.7% reduction in yield. The indices of susceptibility to drought (ISS) and tolerance (IT) classified the lines LUM69, LUM82 and LUM30 as those with the highest tolerance to drought, however, only the LUM69 line showed competitive yields in both irrigation and drought. Based on the average through humid environments, the LUM80 (3.56 t ha^{-1}) and LUM188 (3.1 t ha^{-1}) lines were the ones with the best yield. Although the ISS and IT indices are an acceptable criterion to identify drought-tolerant genotypes, they were not the best because they do not select the genotypes with the best grain yield under irrigation conditions, so the average must also be considered. grain yield from moisture-limiting and non-limiting environments in order to select the best genotypes with tolerance to drought.

Cited literature

Agrama, H. A. S. and Moussa, M. E. 1996. Mapping QTLs in breeding for drought tolerance in maize (*Zea mays* L.). Euphytica. 1(91):89-97.

Avendaño, A. C. H.; Trejo, L. C.; López, C. C.; Molina, G. J. D.; Santacruz, V. A. y Castillo, G. F. 2005. Comparación de la tolerancia a la sequía de cuatro variedades de maíz (*Zea mays*) y su relación con la acumulación de prolina. Venezuela. Interciencia. 9(30):560-564.

Badu-Apraku, B.; Akinwale, R. O.; Ajala, S. O.; Menkir, A.; Fakorede, M. A. B. and Oyekunle, M. 2011. Relationships among traits of tropical early maize cultivars in contrasting environments. Agron. J. 3(103):717-729. Doi:10.2134/agronj2010.0484.

Bänziger, M.; Edmeades, G. O.; Beck, D. y Bellon, M. 2012. Mejoramiento para aumentar la tolerancia a sequía y a deficiencia de nitrógeno en el maíz: de la teoría a la práctica. Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT). México, DF. 68 p.

Bolaños, J. and Edmeades, G. O. 1993. Eight cycles of selection for drought tolerance in lowland tropical Maize. I. Responses in grain yield, biomass, and radiation utilization. Field Crops Res. 3-4(31):233-252. Doi.org/10.1016/0378-4290(93)90064-T.

Bruce, W. B.; Edmeades, G. O. and Barker, T. C. 2002. Molecular and physiological approaches to maize improvement for drought tolerance. J. Exp. Bot. 366(53):13-25. doi.org/10.1093/jexbot/53.366.13.

Castillo-Gutierrez, A. 2004. Drought tolerance and genetic diversity among tropical maize inbred lines. Doctoral Dissertation. University of Nebraska-Lincoln. Lincoln, NE, USA. 112 p.

CONAZA. 2010. Comisión Nacional de Zonas Áridas. Unidad de sequía, desertificación y proyectos especiales. Boletín divulgativo núm. 2. www.conaza.gob.mx.

Edmeades, G. O.; Bolaños, J; Chapman, S. C.; Lafitte, H. R. and Bäzinger, M. 1999. Selection improves drought tolerance in tropical maize populations: I. Gains in biomass, grain yield, and harvest index. Crop Sci. 5(39):1306-1315.

Esparza, M. 2014. La sequía y escasez de agua en México. Situación actual y perspectivas futuras. Secuencia. 89:195-219.

Estrada, P. W.; Jerez M. E.; Nápoles, G. M. C.; Sosa, R. A.; Maceo, R. Y. C. y Cordoví, D. C. 2016. Respuesta de cultivares de frijol (*Phaseolus vulgaris* L.) a la sequía utilizando diferentes índices de selección. Cultivos Tropicales. 3(37):79-84. Doi.org/10.13140/RG.2.1.5181.2082.

Fischer, K. S.; Edmeades, G. O. and Johnson, E. C. 1989. Selection for the improvement of maize yield under moisture-deficits. Field Crops Res. 3(22):227-243. Doi.org/10.1016/0378-4290(89)90094-4.

Fischer, R. A. and Maurer, R. 1978. Drought resistance in spring wheat cultivars. Grain yield responses. Aust. J. Agric. Res. 29(5):897-912. Doi.org/10.1071/AR9780897.

Golbashy, M.; Ebrahimi, M.; Khavari, K. S. and Choukan, R. 2010. Evaluation of drought tolerance of some corn (*Zea mays* L.) hybrids in Iran. Afr. J. Agric. Res. 19(5):2714-2719.

INEGI. 2008. Instituto Nacional de Estadística Geográfica e Informática. Anuario Estadístico de Morelos. 1[a] (Ed.). Editorial. México, DF. Tomo II. 461 p.

INIFAP. 2017. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Reporte estación. http://clima.inifap.gob.mx/.

López, S. E.; Tosquy, V. O. H.; Ugalde, A. F. J. y Acosta, G. J. A. 2008. Rendimiento y tolerancia a sequía de genotipos de frijol negro en el estado de Veracruz. Rev. Fitotec. Mex. Núm. Esp. 3(31):35-39.

Khalili, M.; Reza, N. M.; Pour, A. A. and Naseri, R. H. 2013. Effects of drought stress on yield and yield components in maize cultivars (*Zea mays* L.). Intl. J. Agron. Plant. Prod. 4(4):809-812.

Messina, D. C.; Sinclair, R. T.; Hammer, L. G.; Curan, D.; Thompson, J.; Oler, Z.; Gho, C. and Cooper, M. 2015. Limited-transpiration trait may increase maize drought tolerance in the US corn belt. Agron. J. 6(107):1978-1986. doi:10.2134/agronj15.0016.

Mohammadi, R. 2016. Efficiency of yield-based drought tolerance indices to identify tolerant genotypes in durum wheat. Euphytica. 1(211):71-89.

FAO-SAGARPA. 2012. Organización de las Naciones Unidas para la Alimentación y la Agricultura-Secretaría de Agricultura Ganadería, Desarrollo Rural Pesca y Alimentación. México: el sector agropecuario ante el desafío del cambio climático. México, DF. 439 p.

Ribaut, J. M.; Hoisington, D. A.; Deutsch, J. A.; Jiang, C. and Gonzalez-de-Leon, D. 1996. Identification of quantitative trait loci under drought conditions in tropical maize. 1. Flowering parameters and the anthesis-silking interval. Theor. Appl. Genet. 7(92):887-896.

Ribaut, J. M.; Jiang, C.; Gonzalez, d L. D.; Edmeades, G. O. and Hoisington, D. A. 1997. Identification of quantitative trait loci under drought conditions in tropical maize. 2. Yield components and marker-assisted selection strategies. Theor. Appl. Genet. 7(94):887-896.

Rosielle, A. A. and. Hamblin, J. 1981. Theoretical aspects of selection for yield in stress and non-stress Environments. Crop Science. 6(21):943-946. Doi:10.2135/cropsci1981.0011183X002100060033x.

Saini, H. S. and Westgate, M. E. 2000. Reproductive development in grain crops during drought. In Advances in Agronomy. ed. D. L. Spartes. Academic Press. San Diego, CA, USA. 59-96 pp. doi.org/10.1016/S0065-2113(08)60843-3.

Salinas, Z. C. A.; Lluch, B. D.; Hernández, V. S. y Lluch, C. D. B. 1998. La aridez en el noreste de México. Un análisis de variabilidad espacial y temporal. Atmósfera. 1(11):29-44.

SAS. 2009. Statistical Analysis System Institute. SAS user's guide. Statistics. Versión 8.2. SAS Inst. Cary, N. C.

SIAP-SAGARPA. 2017. Servicio de Información Agroalimentaria y Pesquera. Cierre de la producción agrícola por estado SIAP-SAGARPA. http://www.nube.siap.gob.mx/cierre_agricola.

SMN. 2017. Servicio Meteorológico Nacional. Monitor de sequía en México. http://smn.cna.gob.mx/es/climatologia/monitor-de-sequia/monitor-de-sequia-en-mexico.

Shafiq, S.; Akram, N. A. and Ashraf, M. 2015. Does exogenously-applied trehalose alter oxidative defense system in the edible part of radish (*Raphanus sativus* L.) under water deficit conditions? Scientia Horticulturae. 185:68-75. Doi.org/10.1016/j.scienta.2015.01.010.

Stone, P. J.; Wilson, D. R. and Reid, J. B. 2001. Water deficit effects on sweet corn. I. water use, radiation use efficiency, growth, and yield. Aust. J Agric Res. 52(1):103-113. Doi.org/10.1071/AR99146.

Trujillo, C. A. 2002. Guía para cultivar maíz bajo condiciones de riego en el estado de Morelos. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP)-Centro de Investigación Regional del Centro Campo Experimental Zacatepec. 19 p.

Walsh, B. 2001. Quantitative genetic. Encyclopedia of life sciences. Nature Publishing Group. 1-7 pp.

Westgate, M. E. and Boyer, J. S. 1986. Reproduction at low silk and pollen water potentials in maize. Crop Sci. 5(26):951-956. Doi:10.2135/cropsci1986.0011183X002600050023x.

Zambrano, Z. E. E.; Limongi, A. J. R.; Alarcón, C. F. D.; Villavicencio, L. J. P.; Caicedo, V. M. B.; Eguez, M. J. F. y Zambrano M. J. J. 2017. Interacción genotipo de híbridos de maíz bajo temporal en Manabí y los Ríos, Ecuador. Espamciencia. 1(8):7-14.