SELECTION FOR DROUGHT RESISTANCE IN MAIZE

by

A. ORDAS

Misión Biológica de Galicia, C. S. I. C., Pontevedra (Spain)

INTRODUCTION

Maize (*Zea mays* L.) is the most important summer crop grown in Galicia (the northwestern corner of Spain). Under optimal conditions hybrids have proved to be much superior to the open-pollinated varieties grown in the area. Nevertheless, I believe that under the usual growing conditions of Galicia hybrids do not take full advantage of their superior potential because they have been developed under no drought stress. In Galicia there is usually a dry period of four to five weeks in midsummer, a time in which the maize plants are flowering.

A breeding program was started at the Misión Biológica de Galicia (Pontevedra, Spain) in 1975 with three objectives in mind:

1st, to study the variability for drought resistance in the Station's collection of genetic populations.

2nd, to identify inbred lines resistant to drought.

3rd, to obtain hybrids resistant to drought.

This paper describes the results of the first four years of selection.

MATERIALS AND METHODS

Population tests

Sixteen genetic populations were grown at the Misión Biológica de Galicia in 1975 and 1976 *(Table 1)*. A randomized complete block design with two replications was used each year. Two-row plots spaced at 0.80 m consisted of 20 hills per row spaced at 0.50 m. Four kernels per hill were planted and thinned to two plants per hill after emergence. Thus, the final planting density was 50,000 plants/ha.

Manure and mineral fertilizers were added in sufficient amount for the maximum expected yield. During the growing season the experimental plots received the treatments and cultural practices that are usual at the Station with the exception of irrigation. The total rainfall for the period June-August was 28 mm in 1975 and 81 mm in 1976. These amounts are clearly insufficient for the needs of maize and, consequently, it was considered that the experimental plots suffered from drought stress.

Estimates of grain yield, percent moisture at harvest, number of ears per plot, and lodging percentage were obtained in each plot. Yield was recorded as kilograms of ears per plot and adjusted to quintals per hectare of shelled maize at 15.5 % moisture. A random sample of grain from five random ears in each plot was taken, weighed, dried in a forced-air oven at 80° C for five days, and weighed again to determine percent moisture at harvest. The ears per plot were counted and divided by the number of plants to estimate ears per plant. The broken stalks and the root-lodged plants were counted in each plot and divided by the number of plants to obtain lodging percentage.

For each trait a combined analysis of variance over years was calculated following the analysis of variance key-out presented in *Table 2*. Before pooling the individual analysis of variance from each year into the combined analysis, Bartlett's tests for homogeneity of error variances (Steel and Torrie, 1960, p. 347) were computed. There was heterogeneity for yield; consequently, the significance levels for this character must be contemplated with some caution.

Table 1. Populations and inbred lines tested in 1975-76 and 1977-78

Populations				Inbred lines			
1975-76		1977-78		1975-76		1977-78	
Name	Source	Name	Source	Name	Source	Name	Source
Longfellow	Canada	AS-A	Minnesota	68	M.B.G.	EP1	M.B.G.
AS-A	Minnesota	AS-D	»	494	»	EP10	»
AS-B	»	AS-G	»	624	»	EP16	»
AS-Y	»	AS-Y	»	4031	»	EA2087	INIA-Spain
AS-Z	»	Fino	INIA-Spain	EA2087	INIA-Spain	P257	Portugal
Fino	INIA-Spain	H. norteño	»	F2	France	P880	»
Gallego	»	Norteño	»	F7	»	F2	France
H. norteño	»	Tremesino	»	A239	Minnesota	F7	»
Tremesino	»	Vasco	»	A554	»	A239	Minnesota
Monfero	M.B.G.	Abegondo	M.B.G.	A619	»	A554	»
Silleda	»	Laro	»	A632	»	A632	»
Laro	»	Piñeiro	»	A635	»	A638	»
Puis	»	Guillarey	»	A639	»	A639	»
Tuy	»	Parderrubias	»	A641	»	A641	»
Viana	»	Centle	»	C103	Connecticut	A661	»
Villardemilo	»	Villardemilo	»	W22	Wisconsin	W1828	Wisconsin

Table 2. Analysis of variance key-out for each trait combined over locations

Source of variation	df	Expected mean squares (1)
Years (Y)	1	$\sigma^2 + 16\,\sigma^2_{R(Y)} + 16\,r\,\sigma^2_Y$
Reps within years	$2\,(r-1)$	$\sigma^2 + 16\,\sigma^2_{R(Y)}$
Varieties (V)	15	$\sigma^2 + r\,\sigma^2_{VY} + 2\,r\,\frac{\Sigma(\tau-\bar{\tau})^2}{15}$
V x Y	15	$\sigma^2 + r\,\sigma^2_{VY}$
Pooled error	$30\,(r-1)$	σ^2
Total	$32\,r-1$	

(1) Years and replications were considered random effects; varieties was considered a fixed effect.

In 1977 and 1978 a new group of 16 populations was tested *(Table 1)*. This group was formed by some new populations plus the populations selected after the results of 1975 and 1976.

The experimental design was similar to that described above with some minor differences. Three replications were used each year. In 1977 there were 13 hills per row in the experimental unit. In 1978 each row in a experimental unit consisted of 8 three-plant hills spaced at 0.80 m for a planting density of approximately 47,000 plants/ha.

The total rainfall for the period June-August was 213 mm in 1977 and 66 mm in 1978. Although at the first sight it may seem that the amount of rainfall in 1977 was rather high, we should consider the low water-holding capacity of the soil on which the experiment was carried out. Consequently, we can assume that the experimental plots suffered from drought stress at least to some extent.

Bartlett's tests for homogeneity of error variances between years showed heterogeneity for percent moisture.

Inbred line tests

Inbred tests, carried out from 1975 through 1978, followed exactly the same pattern of the population tests with the only difference that two replications were used instead of three in 1977 and 1978.

Bartlett's tests showed heterogeneity of error variances for lodging percentage in 1975-76 and for yield and ears per plant in 1977-78.

Development of inbred lines resistant to drought

In 1975 selfing was initiated on six populations known to be somewhat tolerant to drought. The nursery was placed in a plot with low water-holding capacity and did not receive any watering during the growing season. The inbred development followed the standard method (Jugenheimer, 1976).

The populations selected after the combined analysis of the population tests of 1975 and 1976 were added to the nursery in 1977.

Hybrid test

In 1977 some hybrids were obtained between inbreds selected as drought resistant after the trials of 1975 and 1976, and S_2's from the drought selfing nursery. In addition, some open-pedigree hybrids from the University of Minnesota involving lines resistant to drought were developed. These experimental hybrids, along with some commercial hybrids usually grown under dry conditions by farmers in the area, were arranged in a test in 1978. Two open-pollinated varieties were included in the test. The experimental design was that used for the population test in that year.

Separation of the means was made following the cluster analysis of Scott and Knott (1974).

A general scheme of the selection process is given in *Figure 1.*

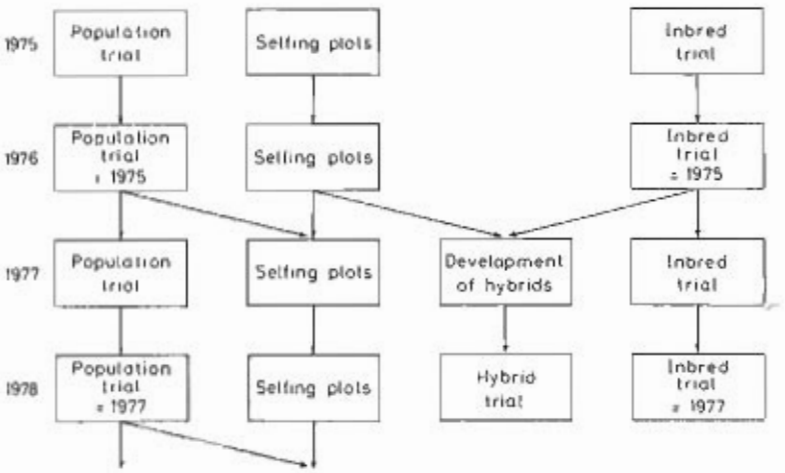

Figure 1.– General scheme of the selection process.

RESULTS AND DISCUSSION

An obvious step in a breeding program aimed at obtaining hybrids resistant to drought is to identify populations that seem to be promising sources of inbred lines.

Yield is the most important selection criterion in the first phases of a breeding program. In the 1975-76 combined analysis of variance *(Table 3)* all of the observed yield differences among populations were due to the interaction varieties $\times$ years. However, in this particular case the individual analyses of variance should be considered. In 1975 the test was placed on a heterogeneous plot. Consequently, the standard error per plot was so big that no differences in yield could be detected. In 1976 the test was placed on a less heterogeneous plot and highly significant differences in yield among populations were observed. For these reasons the best populations from the combined analysis were selected for new testing in the following years and for extraction of inbred lines from them. Significant differences among populations were found for percent moisture, ears per plant, and lodging percentage.

Table 3. Analyses of variance for four traits for the populations tested in 1975 and 1976

Source	df	Mean squares			
		Yield q/ha	Moisture %	Ears/plant	Lodging %
Years (Y)	1	1052.19	46.76	0.4048*	4664.89
Varieties (V)	15	49.69	84.92**	0.0412	990.54**
V x Y	15	45.92*	3.59	0.0132*	195.63
Pooled error	30	20.52	2.84	0.0058	109.15

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

In the combined analysis of variance for 1977-78 *(Table 4)* significant differences among populations were observed for all four traits (i. e. yield, percent moisture, ears per plant, and lodging percentage). Hence, the best populations are picked out to be selfed in 1979 and tested again along with new populations.

Table 4. Analyses of variance for four traits for the population tested in 1977 and 1978

Source	df	Mean squares			
		Yield q/ha	Moisture %	Ears/plant	Lodging %
Years (Y)	1	5499.45**	700.38**	0.1617**	214.50*
Varieties (V)	15	165.37*	96.99**	0.0210**	598.23*
V x Y	15	60.84	3.38	0.0086	240.11**
Pooled error	60	33.91	3.48	0.0058	41.63

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

There are two major avenues through which breeding for drought resistance can be approached (B l u m, 1974). First,

yield and drought resistance are considered to be controlled by separate and individual genetic entities. Second, breeding for conditions of drought is performed under the assumption that a high-yielding genotype under optimal conditions will also perform well under stress conditions.

The two approaches were used in the experiment reported here. The first approach was to test populations and self those more resistant to drought. The second approach was to test inbred lines that were known to be elite under optimal conditions. In *Tables 5* and *6* analyses of variance for the inbred lines are

Table 5. Analyses of variance for four traits for the inbred lines tested in 1975 and 1976

Source	df	Mean squares			
		Yield q/ha	Moisture %	Ears/plant	Lodging %
Years (Y)	1	61.82*	60.75	0.6123**	383.67**
Varieties (V)	15	117.05*	164.10**	0.3127**	1472.74**
V x Y	15	42.25**	7.83**	0.0554**	171.46**
Pooled error	30	12.16	1.68	0.0134	29.31

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 6. Analyses of variance for four traits for the inbred lines tested in 1977 and 1978

Source	df	Mean squares			
		Yield q/ha	Moisture %	Ears/plant	Lodging %
Years (Y)	1	1860.84	126.84**	0.7810**	192.52
Varieties (V)	15	99.36*	124.62**	0 0794	793.42**
V x Y	15	56.07	5.16*	0 0431	161.10
Pooled error	30	42.66	2.28	0 0216	114.33

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

presented. Significant differences among them were observed for all of the characters under study with the exception of ears per plant in 1977-78. These results show that an outstanding inbred under optimal conditions might be a poor genotype under drought stress.

The advantage of selfing and selecting inbred lines under drought conditions is made clear from the analysis of *Table* 7. Three out of the five top hybrids involved S_2 lines from the drought selfing nursery. These hybrids, namely HN-4-2 × A239, (A639 × A641) P-18-1, and ASB-11-2 × EA2087, yielded 128, 121 and 117 percent, respectively, of the mean of the commercial hybrids. It should also be pointed out that the best entry in the test, i. e. Minhybrid 7301, involves two inbreds that were outstanding in the inbred tests reported above.

Table 7. Means for yield, percent moisture, ears per plant, and lodging percentage for 16 hybrids grown in 1978

Pedigree	Type of hybrid	Yield q/ha	Moisture %	Ears/plant	Lodging %
Minhybrid 7301	3-way	84 a (1)	26.1 b	1.06 a	11 a
HN-4-2 x A 239	Single	74 a	34.0 d	1.05 a	4 a
Minhybrid 6304	3-way	73 a	30.0 c	0.99 a	3 a
(A 639 x A 641) P-18-1	3-way	70 a	24.3 b	1.07 a	4 a
ASB-11-2 x EA 2087	Single	68 a	27.6 c	1.19 a	0 a
Minhybrid 8201	Single	67 a	21.0 a	1.01 a	12 a
Prodes 268	Double	64 a	24.8 b	1.05 a	21 b
M. B. G. 5-8	Double	61 a	28.4 c	0.94 a	12 a
Dekalb 57	Double	59 a	28.3 c	1.04 a	5 a
ASA-22-1 x EA 2087	Single	58 a	29.9 c	1.01 a	4 a
Adour-250	Double	49 b	25.5 b	1.00 a	15 a
(F 7 x F 2) V-8-1	3-way	46 b	22.1 a	1.08 a	30 b
(F 7 x F 2) V-1-1	3 way	45 b	22.0 a	1.01 a	27 b
Laro	—	45 b	24.5 b	0.98 a	43 b
Villardemilo	—	42 b	23.1 a	1.03 a	26 b
(F 7 x F 2) V-34-1	3-way	4	20.1 a	1.01 a	35 b
Average		59	25.7	1.03	16
S. E.		7	1.3	0.05	5

(1) Means followed by the same letter in each column are not significantly different at the 5 % level of probability by Scott-Knott's test.

A comment is needed on the fact that the five last places in the yield ranking were occupied by the two open-pollinated varieties included in the study along with three hybrids of S_2 lines from the drought selfing nursery. These three hybrids were much earlier than most of the other entries in the test and so they were handicapped. The only hybrid with a similar naturity was Minhybrid 8201, which is an outstanding hybrid even in comparison with much later hybrids.

Gupta and Kovács (1974) found that single crosses were more drought resistant than three-way crosses and these in turn more resistant than double crosses. As in the experiment reported here the different kinds of hybrids involved different sets of inbreds, no definite conclusion can be reached is this sense. It seems, however, that for this particular set of hybrids there is no relationship between type of hybrid and degree of drought resistance.

There was found no significant correlation ($r = -0.15$) between the percentage of protein and degree of resistance to drought *(Table 8)*. This result is in disagreement with the finding of Kirtoka and Pecherskaya (1973) which reported that two high-protein forms were more drought resistant than a low-protein line.

For the breeding objective of developing hybrids resistant to drought, I would recommend a two-stage system. The first stage would be to test under drought conditions all of the inbreds in the breeder's collection in order to identify lines resistant to drought. Obviously, hybrids from the selected lines would be developed and tested. The second stage would be to test under drought conditions several populations and to self those selected for drought resistance. This second stage might be carried out simultaneously with the first stage.

Table 8. Percentage of protein and drought resistance rating of several inbred lines

Inbred	Protein (1) %	Rating (2)
68	13 4	1
404	11.3	1
624	15.8	1
EP1	13.7	1
EA2087	11.6	2
F2	13.4	2
F7	13.6	2
A239	12.0	3
A554	14.0	2
A619	11.4	1
A632	12.3	3
A635	11.9	1
A638	12.8	3
A639	11.2	3
A641	12.2	2
C103	11.5	1
W22	12.1	1

(1) Mean of two years
(2) 1 = not resistant
2 = somewhat resistant
3 = resistant.

SUMMARY

In Galicia, where maize (*Zea mays* L.) is the most important summer crop, there is usually a dry period of four to five weeks in midsummer. Several genetic populations and inbred lines were tested at the Misión Biológica de Galicia (Pontevedra, Spain) under drought conditions from 1975 through 1978. Significant differences were found for yield, percent moisture at harvest, number of ears per plant, and lodging percentage at harvest. In addition, several hybrids involving S_2 inbreds developed under

drought stress, along with some commercial hybrids, were tested in 1978. Three experimental hybrids yielded 128, 121, and 117 percent of the mean of the commercial hybrids.

It is suggested that hybrids between inbreds selfed under drought stress be developed and tested as a means for obtaining hybrids resistant to drought.

RESUMEN

En Galicia, donde el maiz (*Zea mays* L.) es el cultivo de verano más importante, hay normalmente un período seco de unas cuatro o cinco semanas hacia la mitad del verano. Diversas poblaciones y líneas puras fueron ensayadas en condiciones de sequía de 1975 a 1978 en la Misión Biológica de Galicia (Pontevedra, España). Se encontraron diferencias significativas para rendimiento, porcentaje de humedad en la recolección, número de mazorcas por planta y porcentaje de encamado en la recolección. Además se ensayaron en 1978 diversos híbridos obtenidos a partir de líneas S_2 autofecundadas en condiciones de sequía junto con varios hibridos comerciales. Tres híbridos experimentales produjeron 128, 121 y 117 por 100 de la media de los híbridos comerciales.

Se sugiere el desarrollo de híbridos entre líneas autofecundadas en condiciones de sequía como medio de obtener híbridos resistentes a la sequia.

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