Morphological classification of maize landraces from northern Spain

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ABSTRACT

One hundred landraces of maize from Northern Spain were characterized on the basis of twenty-two morphological traits, and seventeen ecological variables (climatic, edaphic and topographic) associated with the collection site. High broad-sense heritabilities (>0.6) were found for plant height, ear height, ear node number, ear length, mid-ear diameter, rows of kernels, kernels per row, cob weight and days to silking. Seven different groups were obtained with cluster analysis using plant and cycle traits, and discriminant analysis showed that leaf area, ear shape, tassel branches, rows of kernels, plant height, cob weight, and ear length were the most important traits for taxonomic classification. Seven populations with promising breeding value were detected.

INTRODUCTION

Maize local populations have been cultivated for a long time under natural and human selection in different environments and cultural methods. The interest for preserving its germplasm is enhanced because of the narrow genetic base of most of the cultivated varieties in temperate zones. The replacement of traditional germplasm by material from the Corn Belt is observed in commercial cultivars as well as in breeding programs (Malvar et al., 1996). Furthermore, many hybrids grown in Europe are crosses between U.S. Corn Belt lines and European flint lines, and only a few flint inbreds are used extensively in Europe (Moreno-González, 1988).

The use of local populations could be useful in increasing the genetic variability of maize in temperate zones. This justifies the continued characterization and evaluation of the different landraces and populations stored in the germplasm banks of many research centres in the world.

The effective use of maize landraces in breeding programmes is facilitated by a good taxonomic description. Multivariate analyses (e.g., cluster analysis, principal component analysis and discriminant analysis) for measuring the degree of divergence among populations has been useful in different fields of research, and allows to obtain a summary of the most relevant characteristics. Populations can be grouped together based on informative data which can be used directly in a breeding programme.

Environmental factors have influenced the genetic constitution of landraces during the process of domestication, as shown by the relationships between plant morphology and the ecology of a specific collecting area. Environmental parameters have been used to choose areas

representing different environments for agronomic trials (Ford & Nielsen, 1982), to group genetic diversity (Ruiz de Galarreta & Alvarez, 1994), and to classify testing locations (Pollak & Pham, 1989). The use of these environmental variables also permits estimation of the adaptation possibilities of the local populations for breeding purposes, and can be useful as an additional criterion for classifying the populations. In maize the relationship between environmental parameters and yield has also been studied. Dirks & Bolton (1981) related water availability, heat units and water stress to yield, and Binford et al., (1992) described a relation between yield and physical characteristics of the soil, such as nitrate content.

Spanish germplasm has been useful as breeding material for temperate zones. Sánchez-Monge (1962) made a morphological and agronomical description of the main races cultivated in Spain. Numerical taxonomy techniques have been applied to the study of the morphological variation of local varieties (Alvarez & Lasa, 1990; Llauro & Moreno-González, 1993; Ordás et al., 1994;). Sufficient variability has been detected in all previous studies to indicate that Spanish landraces could be used as a source of new inbred lines. Ron & Ordás (1987) estimated the genetic variance for some traits in landraces from northwestern Spain and Ordás (1991) studied the relationships between Spanish and Corn Belt germplasm.

The objectives of this study were: (1) to characterize and choose the plant trait variables that best explain genetic variation; (2) to group one hundred Spanish maize landraces by numerical taxonomy methods; and (3) to identify the best populations with promising breeding value.

MATERIALS AND METHODS

Plant material

One hundred landraces of maize from Guipúzcoa, in northern Spain, collected from 1985 to 1989 by the technical services of the Diputación Foral of Guipúzcoa, were evaluated. Collections (about 3270 samples) were made directly from the farmer's fields. About 45 ears were collected from each field and an effort was made to include in this number a good representation of the variation in plant and ear type. The collection area was located between latitude 42° and 43°N and longitude 1° and 2°W (Figure 1). Annual rainfall varied from 1000 mm to 2000 mm and annual mean temperature was from 10°C to 14.5°C. The soil types were Vertic Cambisols, Calcic Luvisols, Chromic Luvisols, Acrisols and Rendzina, according to the classification of the Soil Survey Staff (1988). The accessions and their geographical origin are listed in Table 1.

TABLE 1

Evaluation trials

An experimental design of randomised blocks and three replications at two locations in Spain during two years was used. Evaluations were carried out in Fuenterrabía (Guipúzcoa, 43°21'24"N, 1°53'52"W), with an average rainfall of 1600 mm and high soil fertility, and in Zaragoza (41°44'30"N, 0°47'00"W), in a maize growing area with average rainfall of 330 mm and high organic matter content in the soil. The experimental plot included two 5-m rows spaced 0.75 m apart, for an established plant density of about 74100 plants ha⁻¹. The trials of Zaragoza were irrigated throughout the growing seasons to supplement the low natural rainfall. Fertilizer (N-P-K, 12:24:8) was applied at the rate of 400 kg/ha in Fuenterrabía and 600 kg/ha in Zaragoza. Urea fertilizer was added four weeks after seedling emergence to supply an additional 300 kg/ha

and 200 kg/ha, respectively. Weeds were controlled by the application of a mixture of 1.5 kg/ha metolachlor and 0.95 kg/ha atrazine. Granular insecticide treatments (tricolorfon 2.5%) were applied to guarantee protection against stem borer attacks. Data on plant traits were recorded for 10 plants per plot, randomly selected in each plot.

FIG. 1

Based on previous research (Sánchez-Monge, 1962; Camussi et al., 1983; Llaurodo & Moreno-González, 1993, Ordás et al., 1994) and IBPGR descriptors (IBPGR, 1980), twenty-two traits were chosen for evaluation.

Plant height was measured from ground level to the tassel tip. Total leaf number, ear height, and ear node number were measured after flowering. Leaf area was calculated by the formula $A=(L) \times (W) \times (0.75)$, where A =leaf area, L =leaf length, and W =maximum width leaf (Pearce et al., 1975). Tassel length was measured from the point of origin of the lowermost branch to the tip of the central spike, and all primary, secondary and tertiary branches were counted, independently of their size. We determined the conicalness -ear shape- by the formula $C=[(D_i-D_s)/2] \times 100 / [L/3]$, where D_i is the lower diameter, D_s is the upper diameter, and L is the ear length, as explained by Ordás & Ron (1988). Heat units from sowing to silking were calculated by the formula $HT= [(T_{max} + T_{min})/2] - 10$, according to the method of Gilmore & Rogers (1958).

Seventeen climatic, edaphic and topographic parameters were studied. The climatic variables represent average values for the last twenty years in the collecting area. Annual temperature, annual rainfall, potential evapotranspiration and altitude above sea level were obtained from the National Institute of Meteorology of Spain. The edaphic and topographic parameters were based on geomorphologic and edaphic measurements carried out throughout the

maize area in Guipúzcoa (Salazar et al., 1991). Several soil samples were taken and analyzed for edaphic variables. Contents of organic matter, clay, sand and silt were determined according to Nicolás (1968). Ionic concentration and basic saturation of soils were obtained using the methods of Chapman & Pratt's (1981).

Statistical analysis

Combined analyses of variance were performed across locations. Broad-sense heritability for each plant trait was calculated as:

$$H = s^2_G / s^2_P = s^2_g / (s^2_g + s^2_{gy} + s^2_{gl} + s^2_{gyl} + s^2_e)$$

s^2_G = genotypic variance	g = genetic
s^2_P = phenotypic variance	y = year
s^2_e = environmental variance	l = location

Constancy of a trait (Ron & Ordás, 1987) indicates its stability over a number of different environments. It is estimated as:

$$C = s^2_G / s^2_e = s^2_g / (s^2_{gy} + s^2_{gl} + s^2_{gyl} + s^2_y + s^2_l + s^2_{yl} + s^2_e)$$

For this study we consider that the use of both variance components, heritability and constancy, to choose the most appropriate traits for germplasm classification, is more efficient than the use of only one. The errors, associated with the estimates of C and H, were calculated using Dickerson's method described by Hallauer & Miranda-Filho (1988).

All data were transformed into standardized units to eliminate the differences in the units of measurement of each variable (Sneath & Sokal, 1973). Before clustering a principal components analysis was carried out in order to find uncorrelated composited variables. Cluster analyses based on morphological traits were done by the unweighted pair group method using arithmetic averages (UPGMA), with euclidean distances as the measures of the dissimilarity among populations. For the grouping of the populations the agglomerative and hierarchical

method was applied. Finally, canonical discriminant analysis and stepwise discriminant analysis (Judez, 1989) were carried out to analyze the relationships among the groups and to identify a subset of traits and variables that best distinguished differences among populations. Morphological variables for inclusion were selected stepwise to minimize Wilk's lambda between groups. All computations were performed using the SAS package (SAS, 1989).

RESULTS AND DISCUSSION

Table 2 displays the population means and the range for each trait. All characters showed large variation, particularly plant height, ear length, rows of kernels, kernels per rows, cycle traits and grain yield, in which the maximum score was three or four times the minimum. Leaf area showed the largest variation.

TABLE 2

Regarding environmental variables (Table 3), annual rainfall was high in all collection areas. Altitudes ranged from sea level up to 540 m. Among edaphic parameters, organic matter showed large variation. However more than 60% of the populations grew on soils that contained between 4 and 6% organic matter. Considering the parameters that define soil texture (Primo & Carrasco, 1981), over 80% of the populations were collected from areas with soils with medium-high sand content. More than 75% of the populations grew on soils that are highly acid, and 10% on extremely acid soils. The content of calcium showed a wide range, though most of the populations were from soils with intermediate content (Nicolas, 1968). Other nutrients such as magnesium, sodium and potassium showed average values for acid soils (Briggs, 1977). Cation exchange capacity value depends on soil composition and texture displayed a broad range of

values, though many of the populations came from soils with a low cationic exchange capacity. Base saturation showed large variability, reaching values close to 80%.

TABLE 3

Only traits with a heritability value higher than 0.5 and constancy higher than 1.0 were used in this study. Morphological traits low in heritability and constancy were excluded due to their high environmental dependence. The highest values of heritability and constancy were found for some ear traits, such as cob weight, rows of kernels, kernels per row, length and diameter (Table 4). These results agree with those reported by Pego & Hallauer (1984), and Ron & Ordás (1987). Cycle and vegetative traits, such as heat units from sowing to silking, plant and ear height, ear node number, and leaf area also showed high values, which is in agreement with Hallauer & Miranda-Filho (1988). Total number of leaves and tassel traits like length and branch number showed intermediate heritabilities as found also by Geraldi et al. (1985).

TABLE 4

Yield traits, such as 1000 kernel weight, hectoliter weight and grain yield showed lower heritability than morphological traits, which is in agreement with the results of Böhm & Schuster (1985).

Concerning constancy, the highest values correspond to traits with high heritability. Goodman & Paterniani (1969) found the highest value for rows of kernels, which agrees with our results. However, we obtained higher values of constancy for ear length and plant height. These divergences could be explained by the different origins of the analysed germplasm. Similar values for ear shape, tassel length, plant and ear height, and sowing to silking interval were reported by Llauradó & Moreno-Gonzalez (1993).

Sixteen plant traits (Table 5) were chosen for taxonomic classification and discriminant analysis. Seven groups of populations could be distinguished which have the following characteristics:

GROUP 1. The largest group, with 36 populations from most parts of Guipúzcoa. Plants are tall, with long tassels; days to silking range between 67 and 74; ears are long and cylindric with 10 to 14 rows.

GROUP 2. Only one population. Plants are short with many tassel branches. The ear is very cylindric and its length, kernel row number and cob weight are the largest of all the groups.

GROUP 3. Includes five populations located on the coast. Plants are tall, with many leaves, large leaf area and have long branched tassels. Their maturity is the latest of all the groups, and they have the highest mean row number per ear.

GROUP 4. Includes seventeen populations located in inland valleys. Plants are the shortest with the fewest number of leaves, smallest leaf area, with shortest tassels carrying few branches. They are early to mature.

GROUP 5. Twenty-three populations from inland and mountain areas belong to this group. Plants are average in size, and the ears have small diameter with a large number of kernels per row.

GROUP 6. Seventeen populations belong to this group. Tassels are short, ears are short, with a large ear diameter and many rows per ear.

GROUP 7. Only one population, whose main feature is a very conical ear. It is the earliest population, and the plants are short. This population resembles the "Vasco" landrace described by Sánchez-Monge (1962).

TABLE 5

Some of this groups were probably introduced in Guipúzcoa during de last four centuries. The original populations had originated new groups through local adaptation or by hybridization between different varieties, probably due to the continuous interchange and local trade between different localities. This could be some of the reasons of the existence of groups, with intermediate characteristics.

Discriminant analysis was carried out with the seven obtained groups (Figure 2). The first two functions explained 87.8% of the total variation.

FIG. 2

Among the sixteen plant traits, the most important ones for discriminant analysis were in decreasing order: leaf area, ear shape, tassel branches, rows of kernels, plant height, cob weight and ear length (Table 6). Alvarez & Lasa (1990) considered ear traits such as rows of kernels, cob diameter and length, as the most discriminant.

TABLE 6

Our study showed that there are seven landraces which deserve special attention from the breeders' point of view. Populations ZM-725 and ZM-699 have the highest values for kernels per row and grain yield. They grow under high temperature, acid soils and sand, and low values of calcium and magnesium. ZM-822 and ZM-808 have the lowest scores for maturity, 56 and 60 days, respectively, and could be considered as good ones for earliness with intermediate yield (Alvarez & Ruiz de Galarreta, 1999). Population ZM-786 has the highest values for number of leaves (15) and leaf area (1112 cm²). These traits are important in a breeding programme to develop varieties for forage production. Population ZM-915 grows in areas with the lowest average minimum temperature (10°C), soils with the highest organic content, calcium and

magnesium, and has a high grain yield (3.4 t/ha). Only one population, ZM-732, grows on soils with low organic matter content (3.1 %) and the highest scores of clay (6.3%), sodium (0.1 meq) and potassium (0.1 meq). Wide genetic variation was observed in the populations for all plant traits studied. The higher values of heritability are associated with ear traits, such as length, diameter, row number, cob weight, and plant traits such as days to flowering, plant height, ear height and ear node number.

The results of the discriminant analyses suggest that plant traits such as plant height, tassel branches and leaf area, and ear traits such as length, rows of kernels, ear shape and cob weight can be considered appropriate for classification of the northern Spanish maize landraces..

We conclude that the populations used in this study, as representatives of the landraces grown in the Northeast of Spain. The grouping found in this study could be used for the selection of parental stocks from the germplasm collection and for establishing a core collection which includes the genetic diversity in a condensed and manageable, yet representative assembly of accessions. On the other hand, the great range of variation and the heritability for some traits, indicate that good progress could be obtained through an intrapopulation selection program. These populations could enhance the genetic base of breeding programmes in temperate zones, particularly to produce hybrids adapted to European conditions.

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REFERENCES

- Alvarez, A. & J.M. Lasa, 1990. Local populations of maize from the North of Spain. Proc. II National Maize Conference. September 19-21, Grado. Italy. Vol. 2:848-856.
- Alvarez, A. & J.I. Ruiz de Galarreta, 1999. Genotype-environment interaction in maize landraces from northern Spain. *Journal of Genetics & Breeding* 53:177-181.
- Böhm, H. & W. Schuster, 1985. Untersuchungen zur Heritabilität bei Mais (*Zea mays* L.). *Z. Pflanzenzüchtung*, 95:125-134.
- Briggs, D., 1977. *Soils*. Butterworths. London, U.K. pp. 20-23.
- Camussi, A., P.L. Spagnoletti-Zeuli & P. Melchiorre, 1983. Numerical taxonomy of Italian maize populations: genetic distances on the basis of heterotic effects. *Maydica* 28: 411-424.
- Chapman, H.D. & P.F. Pratt, 1981. *Métodos para análisis para suelos, plantas y agua*. Trillas (Ed.). México. pp. 10-27.
- Ford, G.L. & G.A. Nielsen, 1982. Selecting environmentally analogous areas for agronomic research using computer graphics. *Agron. J.* 74: 261-265.
- Geraldi, I.O., J.B. Miranda-Filho & R. Vencovsky, 1985. Estimates of genetic parameters for tassel characters in maize (*Zea mays* L.) and breeding perspectives. *Maydica* 30: 1-14.

- Gilmore, E.C. & J.S. Rogers, 1958. Heat units as a method of measuring maturity in corn. *Agron. J.* 50:611-615.
- Goodman, M.M. & E. Paterniani, 1969. The races of maize: III. Choices of appropriate characters for racial classification. *Econ. Bot.* 23: 265-273.
- Hallauer, A.R. & J.B. Miranda-Filho, 1988. Quantitative genetics in maize breeding. Iowa State Univ. Press. Ames, Iowa, USA. p. 611
- IBPGR, 1980. Maize descriptors. FAO-IBPGR. Roma. pp. 6-8.
- Judez, L., 1989. Técnicas de análisis de datos multidimensionales. M.A.P.A. (Ed.). Madrid. pp. 30-40.
- Llauradó M. & J. Moreno-González, 1993. Classification of northern Spanish populations of maize by methods of numeral taxonomy. I. Morphological traits. *Maydica* 38: 115-21.
- Malvar, R.A., A. Ordás, P. Revilla & M.E. Carrea. 1996. Estimates of genetic variances in two Spanish populations of maize. *Crop Sci.* 36: 291-295.
- Moreno-González, J., 1988. Diallel crossing system in sets of flint and dent inbred lines of maize (*Zea mays* L.). *Maydica* 33: 37-49.
- Nicolás, A., 1968. Apuntes de Edafología. E.T.S.I.M., Sección de Publicaciones. Madrid. pp. 10-20.
- Ordás, A., 1991. Heterosis in crosses between American and Spanish populations of maize. *Crop. Sci.* 31: 931-935.
- Ordás, A. & A.M. de Ron, 1988. A method to measure conicalness in maize. *Maydica* 33: 261-267.
- Ordás, A., R.A. Malvar & A.M. de Ron, 1994. Relationships among American and Spanish populations of maize. *Euphytica* 79: 149-161.

- Pearce, R.B., J.J. Mock, & T.B. Bailey, 1975. Rapid method for estimating leaf area per plant in maize. *Crop Sci.* 15: 691-694.
- Pego, S.E. & A.R. Hallauer, 1984. Portuguese maize germplasm with abnormal ear shape. *Maydica* 29: 39-53.
- Pollak, L.M. & H. N. Pham, 1989. Classification of maize testing locations in Sub-Saharan Africa by using agroclimatic data. *Maydica* 34: 43-51.
- Primo, E. & J.M. Carrasco, 1981. *Química agrícola I. Suelos y Fertilizantes*. Ed. Alhambra. Madrid.
- Ron, A.M de. & A. Ordás, 1987. Genetic study of non-ear characters in maize. *Plant Breeding* 98: 268-271.
- Ruiz de Galarreta, J.I. & A. Alvarez, 1994. Characterization of Spanish maize populations according to their agroecological zone of origin. *Ann. Aula Dei* 21: 1-85.
- Salazar, A., S. Alonso, J. Gallardo, G. Portero, M.H. Pascual & A. Olive, 1991. Geomorfología y edafología de Guipúzcoa. Diputación Foral de Guipuzcoa. San Sebastián. p.p. 5-99.
- Sánchez-Monge, E. 1962. Razas de maíz en España. Publ. Ministerio de Agricultura. Madrid. p. 179.
- SAS Institute Inc., 1989. *SAS/STAT User's Guide, Version 6, 4th ed., Vols. I and 2*. SAS Institute Inc., Cary, NC, USA.
- Sneath, P.H.A. & R.R. Sokal, 1973. *Numerical taxonomy*. W.H. Freeman and Co. San Francisco, CA, USA. pp. 152-157.
- Soil Survey Staff., 1988. *Keys to soil taxonomy*. SMSS, Technical Monograph. Cornell Univ. USA. p. 220.

Table 1. Maize accessions studied, and their origin.

No.	Geographical origin	Accession number	No.	Geographical origin	Accession number
1	Hondarribia	ZM-690	51	Albiztur	ZM-822
2	Irun	ZM-697	52	Bidegoyan	ZM-823
3	Oyarzun	ZM-699	53	Bidegoyan	ZM-826
4	Oyarzun	ZM-709	54	Regil	ZM-827
5	Lezo	ZM-700	55	Azpeitia	ZM-835
6	Lezo	ZM-701	56	Azpeitia	ZM-839
7	Pasaia	ZM-703	57	Azkoitia	ZM-840
8	Renteria	ZM-712	58	Azkoitia	ZM-843
9	Hernani	ZM-717	59	Azkoitia	ZM-848
10	Urnietia	ZM-722	60	Bergara	ZM-849
11	Andoain	ZM-723	61	Gainza	ZM-874
12	Andoain	ZM-725	62	Lizarza	ZM-854
13	Andoain	ZM-730	63	Lizarza	ZM-856
14	Aduna	ZM-728	64	Alzo	ZM-852
15	Zizurkil	ZM-731	65	Alzo	ZM-861
16	Zizurkil	ZM-732	66	Orendain	ZM-862
17	Villabona	ZM-734	67	Orendain	ZM-863
18	Asteasu	ZM-737	68	Hernialde	ZM-797
19	Anoeta	ZM-743	69	Amezqueta	ZM-864
20	Alkiza	ZM-744	70	Amezqueta	ZM-866
21	Alkiza	ZM-746	71	Abalcisketa	ZM-868
22	Larraul	ZM-748	72	Abalcisketa	ZM-869
23	Zarauz	ZM-766	73	Alegia	ZM-871
24	Usurbil	ZM-755	74	Alegia	ZM-859
25	Usurbil	ZM-758	75	Legorreta	ZM-875
26	Orio	ZM-759	76	Legorreta	ZM-877
27	Aizarnazabal	ZM-780	77	Isasondo	ZM-878
28	Aia	ZM-764	78	Isasondo	ZM-880
29	Aia	ZM-752	79	Arama	ZM-885
30	Donostia	ZM-775	80	Ordicia	ZM-881
31	Donostia	ZM-760	81	Ordicia	ZM-887
32	Getaria	ZM-784	82	Zaldibia	ZM-888
33	Cestona	ZM-786	83	Zaldibia	ZM-891
34	Deba	ZM-787	84	Lazcano	ZM-892
35	Deba	ZM-790	85	Olaberria	ZM-894
36	Motriko	ZM-791	86	Ataun	ZM-897
37	Motriko	ZM-794	87	Ataun	ZM-901
38	Tolosa	ZM-865	88	Idiazabal	ZM-905
39	Tolosa	ZM-799	89	Idiazabal	ZM-909
40	Belaunza	ZM-802	90	Mutiloa	ZM-911
41	Belaunza	ZM-803	91	Cerain	ZM-912
42	Leaburu	ZM-805	92	Segura	ZM-913
43	Ibarra	ZM-806	93	Segura	ZM-914
44	Berrobi	ZM-808	94	Cegama	ZM-915
45	Berrobi	ZM-809	95	Cegama	ZM-919
46	Elduayen	ZM-810	96	Beasain	ZM-921
47	Elduayen	ZM-812	97	Gabiria	ZM-923
48	Berastegi	ZM-815	98	Gabiria	ZM-926
49	Berastegi	ZM-818	99	Ormaiztegi	ZM-927
50	Albiztur	ZM-820	100	Ezkioga	ZM-928

Table 2. Mean, standard deviation (SD), and range of plant traits.

Trait	Mean	SD	Range
Plant height (cm)	189.0	0.30	102.0 - 324.0
Number of leaves	10.2	0.01	6.0 - 15.0
Ear height (cm)	67.0	0.21	17.0 - 149.0
Ear node number	5.6	0.01	3.0 - 9.0
Leaf area (cm ²)	555.0	1.34	110.0 -1112.0
Tassel length (cm)	39.0	0.06	20.0 - 67.0
Tassel branches number	15.0	0.05	3.0 - 53.0
Ear length (cm)	14.8	0.02	7.0 - 24.0
Ear lower diameter (mm)	47.0	0.05	30.0 - 76.0
Ear medium diameter (mm)	44.0	0.05	28.0 - 68.0
Ear upper diameter (mm)	39.0	0.05	21.0 - 62.0
Ear conicalness (%)	10.3	0.04	1.0 - 37.5
Rows of kernels number	11.7	0.02	6.0 - 20.0
Number of kernels per row	27.5	0.04	12.0 - 48.0
Cob weight (%)	27.0	0.15	14.0 - 58.0
1000 kernel weight (g)	370.0	1.62	233.0 - 531.0
Hectoliter weight (kg/Hl)	70.0	0.19	48.0 - 82.0
Grain yield (t/ha)	2.5	0.09	0.9 - 4.1
Grain moisture (%)	15.3	0.14	7.9 - 29.2
Sowing to silking (days)	69.0	0.16	56.0 - 85.0
Heat units to silking (°C)	610.0	2.61	459.0 - 853.0
Anthesis to silking interval (days)	2.4	0.04	0.0 - 9.0

Table 3. Mean, standard deviation (SD), and range of environmental variables.

Variable	Mean	SD	Range
<i>Climatic*</i>			
Mean minimum temperature (°C)	8.0	0.13	5.8 - 10.5
Mean temperature (°C)	12.2	0.12	10.1 - 14.5
Mean maximum temperature (°C)	16.5	0.33	14.3 - 18.7
Rainfall (mm)	1486.0	28.30	1081.0 - 2348.0
Potential evapotranspiration (mm)	576.5	4.32	503.1 - 655.0
<i>Topographic**</i>			
Altitude (m)	229.0	12.45	5.0 - 540.0
<i>Soil**</i>			
Organic matter (%)	5.3	0.13	3.1 - 8.1
pH	5.9	0.07	4.2 - 7.1
Clay (%)	15.6	1.10	6.3 - 38.7
Sand (%)	57.0	1.10	21.2 - 77.5
Silt (%)	28.1	0.70	16.2 - 40.1
Calcium (meq/100 g)	8.9	0.48	2.2 - 25.5
Magnesium (meq/100 g)	1.1	0.06	0.2 - 2.8
Sodium (meq/100 g)	0.3	0.02	0.1 - 1.5
Potassium (meq/100 g)	0.2	0.01	0.1 - 1.1
Cation exchange (meq/100 g)	21.3	0.75	8.3 - 40.7
Base saturation (%)	49.5	1.47	23.5 - 74.2

* over twenty years 1970-1990 (National Institute of Meteorology, Spain)

** Salazar et al. (1991)

Table 4. Heritabilities (H), Constancies (C) and Standard Errors, E(H) and E(C), for plant traits.

Trait	H	E(H)	C	E(C)
Plant height	0.706	0.100	1.632	0.089
Number of leaves	0.585	0.024	1.480	0.200
Ear height	0.695	0.098	1.660	0.095
Ear node number	0.645	0.020	1.484	0.063
Leaf area	0.607	0.086	1.714	0.101
Tassel length	0.502	0.067	1.310	0.018
Tassel branches	0.584	0.082	1.980	0.280
Ear length	0.638	0.059	2.320	0.003
Ear lower diameter	0.623	0.088	1.240	0.076
Ear medium diameter	0.632	0.089	1.004	0.076
Ear upper diameter	0.536	0.076	0.820	0.060
Ear conicalness	0.500	0.059	1.170	0.137
Rows of kernels	0.807	0.110	4.610	0.633
Kernels per row	0.711	0.001	4.050	0.554
Cob weight	0.832	0.066	1.878	0.098
1000 kernel weight	0.448	0.063	0.697	0.097
Hectoliter weight	0.246	0.034	0.280	0.040
Grain yield	0.328	0.045	0.310	0.042
Sowing to silking	0.624	0.088	1.373	0.012
Heat units to silking	0.663	0.093	1.470	0.081

Table 5. Mean values for seven clusters of populations based on plant traits.

Trait	Cluster						
	1	2	3	4	5	6	7
Plant height (cm)	204.0	179.0	201.0	167.0	183.0	186.0	169.0
Number of leaves	10.7	10.2	11.1	9.4	9.9	10.2	9.6
Ear height (cm)	78.0	64.0	81.0	51.0	62.0	66.0	55.0
Ear node number	6.0	5.7	6.4	5.0	5.4	5.6	5.3
Leaf area (cm ²)	608.0	574.0	642.0	463.0	534.0	539.0	511.0
Tassel length (cm)	41.0	39.0	41.0	37.0	39.0	38.0	39.0
Tassel branches	16.2	16.6	21.4	12.6	14.1	14.3	14.1
Ear length (cm)	15.5	17.1	15.4	13.9	14.9	13.5	12.3
Ear lower diameter (mm)	48.0	48.0	50.0	45.0	46.0	49.0	51.0
Ear medium diameter (mm)	46.0	46.0	46.0	41.0	43.0	47.0	47.0
Ear conicalness (%)	9.0	8.0	11.0	9.0	9.0	12.0	15.0
Rows of kernels	12.3	10.7	12.9	10.1	11.0	12.6	11.0
Kernels per row	28.6	28.6	26.5	27.1	28.2	25.1	21.7
Cob weight (%)	28.0	35.0	35.0	24.0	26.0	28.0	31.0
Sowing to silking (days)	71.0	72.0	75.0	65.0	68.0	69.0	65.0
Heat units to silking (°C)	630.0	645.0	682.0	566.0	600.0	606.0	560.0

Table 6. Discriminant analysis. Stepwise order of inclusion of plant traits.

Step	Trait	Wilk's Lambda
1	Leaf area	0.2278
2	Ear conicalness	0.1232
3	Tassel branches	0.0781
4	Rows of kernels	0.0545
5	Plant height	0.0410
6	Cob weight	0.0315
7	Ear length	0.0271

All traits have significance at 0.001 level

FD1: First canonical discriminant function; FD2: Second canonical discriminant function

Figure 2. Discriminant analysis of maize populations based on morphological traits. Each number on the diagram represents the number (No) assigned to each population