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MORPHOLOGICAL CHARACTERIZATION OF NATIVE MAIZE POPULATIONS OF THE RATÓN RACE FROM COAHUILA, MEXICO

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ABSTRACT

Because of its wide distribution and adaptation, the maize Ratón race (*Zea mays* L.) is an important component of the diversity in the state of Coahuila, Mexico. The objective of the present research was to perform a morphological characterization of 83 native populations of the Ratón race and identify a subset that will represent diversity. Populations were evaluated in replicated experiments at two different locations with two planting dates per location. Twenty-six quantitative characters of the plant, tassel, ear and grain were recorded, and 14 additional characters (indices) were calculated as relationships among characters. Phenotypic diversity was examined by principal component and cluster analyses. Differences ($p \leq 0.01$, $p \leq 0.05$) among environments were found for 28 characters and ($p \leq 0.01$) among populations for all characters, due to variation in environments and diversity among populations, respectively. Also, differences were found ($p \leq 0.01$, $p \leq 0.05$) in 38 of the 40 characters in the populations × environments interaction, as a differential response of the populations in the environments. Based on the repeatability index (r > 1.0), 10 characters and nine indices less influenced by the environment were selected for classification. The first two components explained 53.3 % of the total variation and it was established that the vegetative, ear and tassel characters were the most important in describing the variation; this allowed to identify a pattern of diversity associated with the area of adaptation of populations in low - intermediate - transition areas, which reveals that maize variation is closely related to altitude, and temperature and humidity gradients. Based on the dendrogram, a representative subset of the diversity of the Ratón race in Coahuila was obtained, made up of 13 of 83 populations (15.7 %).

Keywords: *Zea mays* L., repeatability index, genetic diversity, representative subset of diversity.

INTRODUCTION

Maize (*Zea mays* L.) has been considered a crop of great importance because it is one of the main sources of food, raw material for fodder, and industry. In Mexico, 59 maize races have been described according to the similarity of their morphological characteristics (Sánchez *et al*., 2000).

In this country, much of the maize diversity is found in the form of native populations in farmers' fields, in a wide range of environments, from sea level to altitudes above 2900 m, and from humid tropical environments to semi-desert conditions (Ruiz-Corral *et al.,* 2008). The diversity observed in maize race traits is the result of farmer-directed selection aimed at meeting their consumption, socioeconomic, and production needs, in addition to adaptation to specific environmental conditions (Rincón-Sánchez and Ruiz-Torres, 2018).

The measurement and analysis of morphoagronomic traits of native maize populations are very useful to know the phenotypic variation among and within races and among populations, and at the same time, to evaluate their stability in the environments (Flores-Pérez *et al*., 2015; Govindaraj *et al*., 2015). Diversity studies in populations considered as variants of a race are of great relevance for defining conservation and use strategies, as well as for the identification of alleles that contribute to improve productivity within regions (Rocandio-Rodríguez *et al*., 2014; Rincón-Sánchez and Ruiz-Torres, 2018). According to passport data, the diversity of native maize in the state of Coahuila is represented by seven races: Celaya, Cónico Norteño, Elotes Cónicos, Olotillo, Ratón, Tuxpeño, and Tuxpeño Norteño.

In terms of frequency, the populations identified as belonging to the Ratón race stand out (35.2 %), in relation to Cónico Norteño (26.3 %), Tuxpeño Norteño (19.0 %), and Tuxpeño (10.3 %), distributed in the different agro-climatic conditions, mainly in rainfed or unirrigated areas. These are recognized for attributes such as drought tolerance, yield stability and earliness (Rincón-Sánchez *et al*., 2010; Rincón-Sánchez and Ruiz-Torres, 2015). Sánchez (2011) classifies the Ratón race within the early tropical maize, which is distributed in northeastern Mexico, at altitudes between 100 and 1300 m; they are short cycle plants with great adaptability and low sensitivity to photoperiod. Available information indicates that the Ratón race is distributed in the states of Tamaulipas, Nuevo Leon and Coahuila, and representative populations of this race have been reported in Chihuahua, Veracruz, San Luis Potosi, Durango, and Zacatecas (CONABIO, 2011). The present research is part of the analysis of the diversity of native maize in the state of Coahuila, Mexico.

In this context, the objectives of this research were to study the diversity of native populations of the Ratón race of Coahuila, based on morphological traits, and to define a representative subset of populations that concentrates the diversity of the race. This study was carried out under the assumption that morphological characterization will allow understanding the diversity between and within populations, and that, based on their interrelationships, it will allow defining a subset that represents the diversity of the Ratón race in Coahuila.

MATERIALS AND METHODS

The genetic material consisted of 83 native populations of the maize Ratón race (R), collected in the state of Coahuila, Mexico (Rincón-Sánchez *et al*., 2010), and in later collecting works (unpublished), 70.0 % of which are creamy white kernels and the rest, mainly yellow variants. In 35.0 % of the populations, variants of other races such as Celaya (RxC) (1), Cónico Norteño (RxCN) (4), Elotes Cónicos (RxEC) (1), Olotillo (RxO) (2), Tuxpeño (RxT) (14), and Tuxpeño Norteño (RxTN) (7) were found.

Populations were grouped according to the altitude of the collection site into low (B) (< 1000 m), intermediate (I) (1001 - 1800 m), and transition (T) (> 1800 m) areas, with 29, 50, and 4, respectively. The agronomic evaluation was conducted at two different locations under irrigation conditions: General Cepeda, Coahuila in 2020 (25° 26′ N; 101° 27′ W, altitude 1450 m, mean annual temperature of 18.4 °C, and mean annual precipitation of 279.9 mm), and at El Mezquite, Galeana, Nuevo León in 2021 (25° 18′ N; 101° 16′ W, altitude 1890 m, mean annual temperature of 15.5 °C, and mean annual precipitation of 416.4 mm).

The experimental material was established under an incomplete block design with α-latice arrangement, in two sowing dates per location, with two replications in furrows of 4 m long at a distance between plants of 0.19 m, and between furrows of 0.85 m. The combination of locations × sowing dates was considered as environments.

The phenological and agronomic data obtained as average per plot were male and female flowering (FM, FF) (d), floral asynchrony (ASI) (d), prolificacy (ears plant^{-1}), and grain yield (Mg ha^{-1}).

The morphological characterization was carried out with average values of plants per plot using some of the descriptors for maize (IBPGR, 1991). Three representative plants from each plot were measured regarding: plant height (APTA) and ear (AMAZ) (cm), length (LHOJA) and width of leaf (AHOJA) (cm) of ear, number of leaves above ear (HAMAZ) (cm), leaf area (AF) (cm^2) of ear, peduncle tassel length (LPED) (cm), length of branched part (LRAM), length of central rachis (LRC) (cm), total tassel length (LESP) (cm), and number of primary spikelets (NESP). The indices: APTA/AMAZ (APTAMAZ), AMAZ/APTA (AMAZPTA), LRAM/NESP (LRAMESP) (cm·num^{-1}), LRAM/LESP (LRAMESP), LPED/LESP (LPEDESP), and LRC/LESP (LRCLESP) were also determined.

Ear and grain data were obtained from three representative and complete ears from each plot: length (LMAZ), ear diameter (DMAZ), and cob diameter (DOLO) (cm), number of rows (NHIL), grains per row (GHIL), ear weight (PMAZ) (g), ear surface (SUPMAZ) (cm^3), and shelling percentage (DESG). The following indices were computed: DMAZ/LMAZ (DLMAZ), DOLO/DMAZ (DOLOMAZ).

From 10 consecutive kernels from the center of each ear, average values of kernel length (LG), kernel width (AG), kernel thickness (EG) (cm), and kernel volume (VG) (cm^3) were obtained. Additionally, the weight of 100 seeds (P100S) (g) expressed at 12 % moisture was obtained. The following indices were obtained: AG/LG (ALGRA), EG/LG (ELGRA), and EG/AG (EAGRA). The ear and grain characters and the relationship between them (indices) are described in IBPGR (1991) and Sánchez *et al*. (1993).

Analysis of variance was performed using the PROC GLM procedure of SAS (SAS Institute Inc., 2018), where the environments, populations, and the populations × environments interaction were considered as fixed effects, all other effects in the model as random.

For the selection of characters used in the classification, the repeatability criterion (r) was used: $r = \sigma^2_P / \sigma^2_A + \sigma^2_{PxA}$ where σ^2_P, σ^2_A and σ^2_{PxA} are the estimators of the variance components of populations, environments, and the populations × environments interaction, respectively.

For the classification analysis, it was considered as a decision rule to accept those characters whose r value was greater than one (r > 1.0) (Sánchez *et al.*, 1993). The estimation of variance components was performed with the PROC MIXED procedure of SAS (SAS Institute Inc., 2018).

The averages of 19 selected characters were standardized by subtracting the mean and dividing by the standard deviation before the calculation of the association among populations. Maize diversity was explored by principal component analysis (ACP) and cluster analysis, both performed with R software (R Core Team, 2021). From the ACP results, a biplot was constructed using the first two principal components. For the second analysis, a distance coefficient (dissimilarity) was calculated, defined by the complement of Pearson's correlation coefficient between pairs of populations ($d_{ij} = 1 - r$). With the resulting matrix, a hierarchical cluster analysis was performed and a dendrogram was generated using the hclust function of the Factoextra package of the R software (Kassambara and Mundt, 2020) through the unweighted paired groups method using arithmetic averages (UPGMA).

Based on the dendrogram, a modified stratified and directional sampling was performed (Rincón-Sánchez and Ruiz-Torres, 2018). This process was initiated by discriminating populations with the lowest values of distance between pairs of populations within groups, thus obtaining an initial representative subset of the total populations. For the selection of populations, in each routine images of ears obtained from each experimental unit were used to corroborate the presence of other races, so that those populations absent of combinations with other races were identified. Subsequently, a new dendrogram was obtained to discriminate populations within those retained in the previous step.

RESULTS AND DISCUSSION

Among evaluation environments (locations × sowing dates) a differentiated performance was found ($p \leq 0.01$ and $p \leq 0.05$) in 28 of the 40 characters studied, except in ASI, APTA, AF, LRAM, LRAM/NESP, LRAM/LESP, LPED/LESP, LRC/LESP, HIL, DOLO, EG/AG, and AG/LG (Table 1), as a result of differences in environmental conditions, sowing dates, and altitude of the study localities. Among populations, differences ($p \leq 0.01$) were found in all characters, as a result of variation within the racial group. In the case of the populations × environments interaction, differences ($p \leq 0.01$ and 0.05) were found in 38 of the 40 characters studied, except in ASI and LRAM/NESP, as a result of the differential response of the populations in the tested environments.

The variation among the populations evaluated is attributable in part to the fact that they come from three different areas of adaptation, at altitudes from 245 to 1834 m:

Table 1. Variance component estimators for populations, environments, and populations × environments interaction, and estimated repeatability coefficients in native populations of the Ratón maize race.

Characters	σ^2_P	σ^2_A	σ^2_{PxA}	r
Male flowering (FM) (d)	33.6787	294.7400	1.9672	0.114
Female flowering (FF) (d)	38.4565	287.1000	2.2689	0.133
Floral asynchrony (ASI) (d)	0.2920	0.0582	0.1465	1.427†
Prolificacy (PRO)	0.0011	0.0029	0.0009	0.294
Grain yield (REND) (Mg ha^{-1})	0.2953	0.5987	0.3504	0.311
Plant height (APTA) (cm)	370.6300	24.2907	88.7929	3.277†
Ear Height (AMAZ) (cm)	348.0100	241.1400	57.1591	1.167†
AMAZ/APTA (AMAZPTA)	0.0017	0.0047	0.0004	0.326
APTA/AMAZ (APTAMAZ)	0.0189	0.0472	0.0087	0.338
Leaf length (LHOJA) of ear (cm)	21.1419	20.7257	11.3506	0.659
Leaf width (AHOJA) of ear (cm)	0.1765	0.1916	0.0465	0.741
Area of the leaf (AF) of the ear (cm^2)	2410.9300	463.0300	1104.0100	1.539†
Number of leaves above the ear (HAMAZ)	0.0778	0.0851	0.0201	0.740
Number of primary spikelets (NESP)	4.0172	1.2366	0.8620	1.914†
Peduncle tassel length (LPED) (cm)	2.9131	1.4392	0.5837	1.440†
Length of branched part (LRAM) (cm)	1.6472	0.0033	0.6249	2.622†
Central rachis length (LRC) (cm)	2.1734	0.8665	0.8594	1.259†
Total tassel length (LESP) (cm)	7.4522	5.0227	3.9007	0.835
LRAM/NESP (LRAMESP) (cm·num^{-1})	0.0063	0.0068	0.0021	0.707
LPED/LESP (LPEDESP)	0.0003	0.0001	0.0001	1.763†
LRAM/LESP (LRCLESP)	0.0005	0.0000	0.0001	4.036†
LRC/LESP (LRCLESP).	0.0002	0.0000	0.0001	2.452†
Number of rows (HIL)	0.8147	0.0458	0.1348	4.512†
Number of grains per row (GHIL)	2.5521	5.5517	0.9913	0.390
Ear weight (PMAZ) (g)	113.1000	1020.4800	200.4300	0.093
Ear length (LMAZ) (cm)	0.2521	1.2822	0.4481	0.146
Ear diameter (DMAZ) (cm)	0.0362	0.0465	0.0133	0.605
Cob diameter (DOLO) (cm)	0.0391	0.0007	0.0056	6.134†
Ear surface (SUPMAZ) (cm^2)	83.7371	638.0300	166.2000	0.104
DMAZ/LMAZ (DLMAZ)	0.0004	0.0001	0.0002	1.509†
DOLO/DMAZ (DOLOMAZ)	0.0008	0.0005	0.0001	1.447†
Shelling percentage (DESG)	0.0006	0.0003	0.0001	1.317†
Grain length (LG) (cm)	0.0018	0.0060	0.0011	0.256
Grain width (AG) (cm)	0.0014	0.0024	0.0006	0.481
Grain thickness (EG) (cm)	0.0002	0.0004	0.0001	0.347
Grain volume (VG) (cm^3)	0.0007	0.0047	0.0006	0.142
AG/LG (ALGRA)	0.0018	0.0001	0.0003	4.151†
EG/LG (ELGRA)	0.0003	0.0001	0.0002	1.164†
EG/AG (EAGRA)	0.0005	0.0000	0.0003	1.761†
Weight of 100 seeds (P100S) (g)	3.1457	22.3264	3.1457	0.257†

† = Characters selected for having r > 1; σ^2_P, σ^2_A and σ^2_{PxA} = variance components in populations, environments, and the populations × environments interaction, respectively; r= repeatability = $r = \sigma^2_P \ / \ \sigma^2_A + \sigma^2_{PxA}$.

Low (34.9 %), Intermediate (60.2 %), and Transition-High (4.8 %). Ruiz-Corral *et al*. (2008) reported a range of adaptations of the Ratón race that varies from 84 to 1300 m, while Sánchez (2011) mentions that it is distributed at altitudes between 100 and 1300 m. On the other hand, 35.0 % of these populations show genetic infiltration from other races, mainly Tuxpeño, Tuxpeño Norteño, and Cónico Norteño, as a consequence of seed exchange among farmers and interbreeding by open pollination. In addition, genetic variation is also attributable to natural and artificial selection processes through multiple generations, practiced by farmers for traits of interest (Rincón-Sánchez *et al*., 2010; Martínez-Sánchez *et al*., 2017).

Repeatability analysis

The genotype × environment interaction is a determining factor in the numerical classification of germplasm, therefore, among other criteria, repeatability indices (r) have been used to identify those traits that are less affected by the environment (Sánchez *et al*., 1993). These authors point out that vegetative characters are the most affected by environmental factors and their interaction, compared to ear and tassel characters, which are considered more useful in the classification of maize populations and races. Based on the criterion of repeatability greater than one ($r > 1.0$) and the above elements, 19 characters (11 characters and eight indices) were chosen and used in the classification analyses (Table 1).

The repeatability index greater than one identifies those traits where the proportion of the variance of the populations is greater than the sum of the variance components due to the environments and the populations × environments interaction, that is, traits that are little influenced by the environment, and therefore, useful for the classification of populations of maize races (Sánchez *et al*., 1993). Rocandio-Rodríguez *et al.* (2014) and Flores-Hernández *et al*. (2022) in studies of high valley maize identified tassel characters (LESP, LRC) and row number similar to those selected in the present work, however, these authors also selected kernel characters (length, width, and thickness) as useful, but in this research, they had repeatability values lower than 0.5.

It is also important to mention that repeatability differs, depending on the nature of the trait, the genetic properties of the population, and the environmental conditions in which the individuals develop (Falconer and Mackay, 1996).

Principal component analysis

The first three principal components (CP) explain 66.9 % of the total variation of the 19 characters identified (Table 2).

The characteristic vectors associated with each principal component are proportional to the correlation coefficient between the original characters and that principal component. Those original characters that had characteristic vectors equal to or greater than 0.5 were considered of greater relevance in explaining the variation among the populations under study, identifying 17 of the 19 characters in the three CPs.

The value of 0.5 was considered in each CP since they are independent. Most of these characters have been reported in other studies of diversity of native maize populations

Table 2. Values and characteristic vectors associated with the first three principal components of the analysis of the characters for morphological description in native populations of the maize Ratón race.

Characters	Characteristic vectors		
	CP1	CP2	CP3
Floral asyncrony (ASI) (d)	0.536*	0.314	-0.133
Plant height (APTA) (cm)	0.609*	0.678*	0.148
Plant height (AMAZ) (cm)	0.691*	0.615*	0.152
Leaf area (AF) (cm^2)	0.774*	0.263	0.262
Number of primary spikelets (NESP)	0.776*	0.325	-0.242
Peduncle tassel length (LPED) (cm)	-0.540*	0.552*	-0.039
Length of branched part (LRAM) (cm)	0.842*	0.267	-0.225
Central rachis length (LRC) (cm)	-0.315	0.397	0.569*
LRAM/LESP (LRAMESP) ($cm \cdot num^{-1}$)	0.911*	-0.005	-0.303
LPED/LESP (LPEDESP)	-0.723*	0.224	-0.241
LRC/LESP (LRCLESP)	-0.371	-0.248	0.670*
Number of rows (HIL)	-0.016	0.412	0.704*
Cob diameter (DOLO) (cm)	0.550*	-0.520*	0.545*
DMAZ/LMAZ (DLMAZ) (cm)	0.203	-0.415	0.502*
DOLO/DMAZ (DOLOMAZ) (cm)	0.504*	-0.700*	0.269
Shelling percentage (DESG) (%)	-0.786*	0.187	-0.239
EG/AG (EAGRA)	-0.217	0.407	0.398
EG/LG (ELGRA)	0.055	-0.405	0.073
AG/LG (ALGRA)	0.249	-0.810*	-0.288
Characteristic values	6.254	3.878	2.585
Explained variance (%)	32.914	20.411	13.605

*= Characters with the highest association with the respective principal component; CP1, CP2, and CP3 = Principal components 1, 2 and 3, respectively.

(González-Martínez *et al*., 2018; Rangel-Lucio *et al*., 2021) and highlighted as important to assess the diversity present among populations at the local level.

In this study, the first two CP were used, which explain 53.3 % of the accumulated variation in the 19 original characters and are the ones that explain the greatest variation. The populations x characters interaction (Figure 1) explains the relationship of the characters with the populations, and their characteristics.

Populations located in the vector direction of a character indicate the close relationship among them (Yan, 2014). The length of the vectors from the origin indicates the variation associated with the character, and the angle between them approaches the correlation coefficient, and therefore, the association between characters: an angle less than 30° indicates a very close relationship, while an independent relationship will be given by an angle close to 90°; an angle of 180° will be representing a negative association (Yan, 2014).

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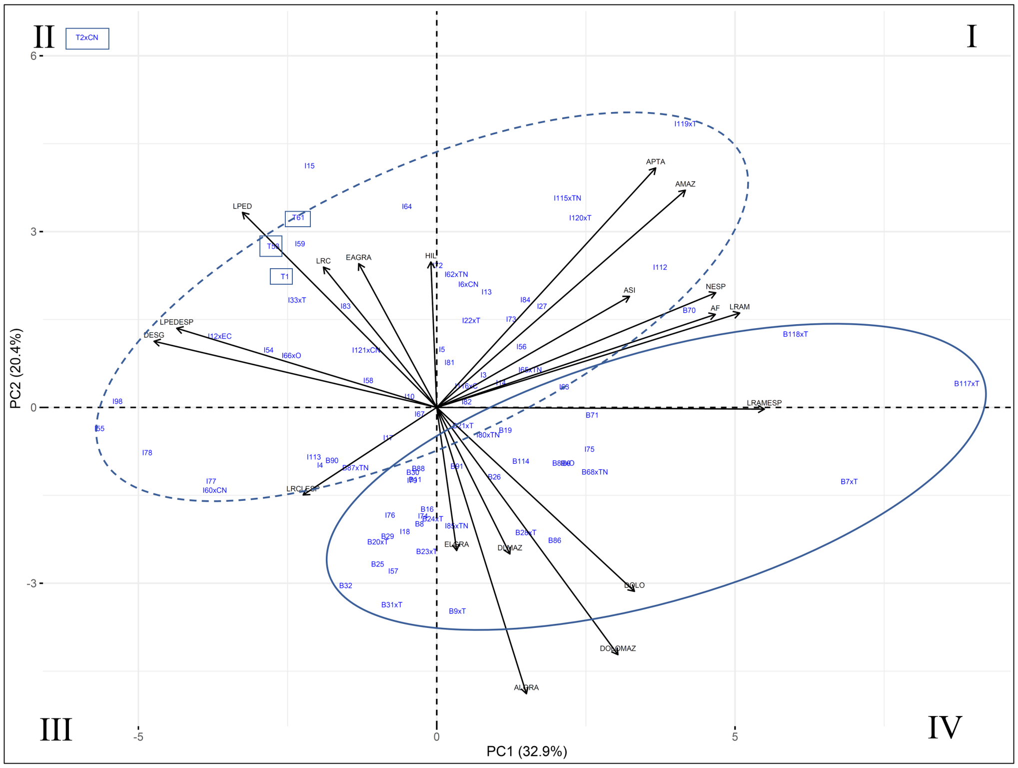

Figure 1. Graphical dispersion of the interaction between populations and characters, based on the first two principal components (CP1, CP2). In the populations, the first character indicates the area of provenance: B=Low, I=Intermediate, and T=Transition; followed by the entry number, and at the end, the combination with another race ("x"): C=Cónico, CN=Cónico Norteño, EC=Elotes Cónicos, O= Olotillo, T=Tuxpeño, and TN=Tuxpeño Norteño; Ellipse solid line = populations from low adaptation areas (< 1000 m); Ellipse dotted line = populations from intermediate adaptation areas (1000 to 1800 m); Rectangles = populations from transitional adaptation areas (> 1800 m).

From the dispersion analysis (Figure 1), it was possible to identify a continuum of variation, basically related to the pattern of the area of origin and adaptation of the populations under study (low - intermediate - transition areas). Similar results were reported by Cabrera-Toledo *et al.* (2019) who also mention that the degree of adaptation to the localities is manifested in the similarity of the populations, associated with different collecting altitudes.

In the direction from intermediate areas to the transition area (> 1000 m) (second quadrant), populations are characterized by higher values peduncle tassel length LPED and DESG, and lower values in DOLO compared to populations in low areas (< 1000 m) (fourth quadrant). Populations with positive values in APTA and AMAZ, AF of ear leaf, LRAM, and NESP of tassel are located in the first quadrant, while those with negative values are located in the opposite direction (third quadrant).

In the group indicated as low areas (Figure 1), populations of the Ratón race were identified in combination with the Tuxpeño and Tuxpeño Norteño races; while in the intermediate areas, in addition to these two races, the combination of the Ratón race with the Celaya, Cónico Norteño, Olotillo, and Elotes Cónicos race was identified. Rincón-Sánchez *et al*. (2010) point out that the combination among races contributes to explain the phenotypic variation among populations and the diversity of maize in the region, originated in part by the exchange of seeds among farmers, genetic recombination through open pollination in later generations, and adaptation to specific environments.

Cluster analysis

The dendrogram (Figure 2) corresponded in general to the pattern observed (Figure 1), where two large groups were also identified, at a distance of 1.1: Group 1, made up of populations from the low adaptation area (41 populations), and Group 2, mainly from the intermediate adaptation area (42 populations).

At a distance of 0.9 units, four subgroups of populations are distinguished, two of them (AB1 and AB2) to Group 1 and two (AI1 and AI2) to Group 2. In the latter, in subgroup AI1, the four populations identified with the transitional adaptation area (> 1800 m) are included. The average values of the characters under study for the four subgroups obtained from the dendrogram analysis are presented (Table 3).

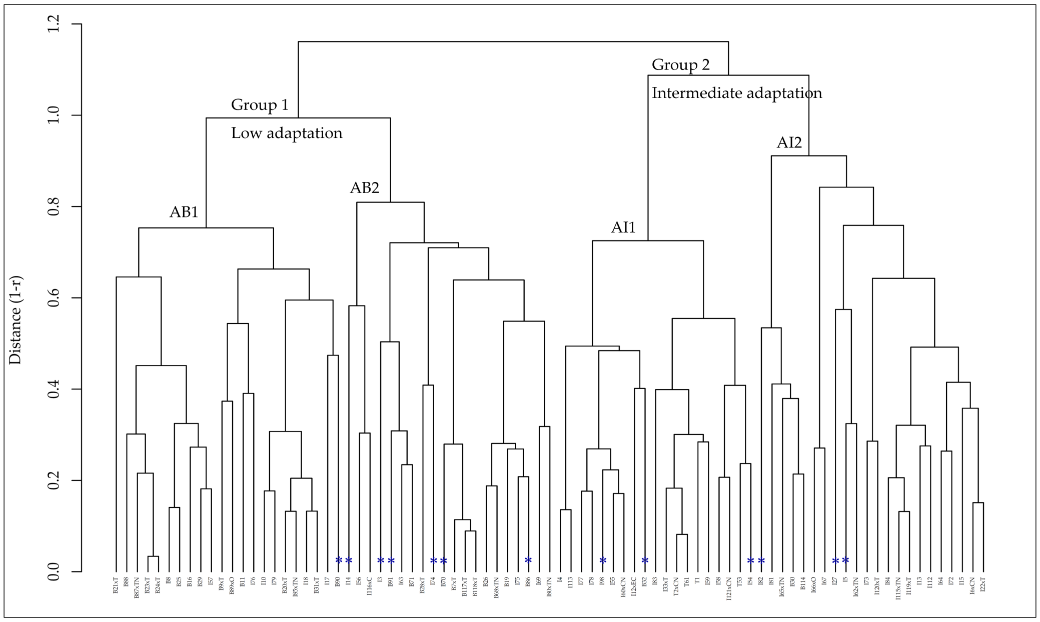

Figure 2. Dendrogram of 83 native populations of the Ratón race of Coahuila, using the correlation complement as distance (1 - r) and the pairwise grouping method based on arithmetic averages (UPGMA); * = Populations of the representative subset of diversity.

Table 3. Averages of the characters evaluated in four groups identified in 83 populations of maize of the Ratón race in Coahuila, México.

Characters	Groups† AB1	AB2	AI1	AI2	Media	DMSH Tukey
Number of populations	22	20	19	22		
Floral asyncrony (ASI) (d)	1.22 b¶	1.94 a	1.44 b	1.82 a	1.61	0.366
Plant height (APTA) (cm)	187.58 d	208.31 b	191.65 c	213.47 a	200.25	3.796
Plant height (AMAZ) (cm)	105.48 b	125.37 a	104.39 b	126.69 a	115.48	3.479
Leaf area (AF) (cm^2)	544.03 b	589.87 a	495.51 c	559.73 b	547.29	16.659
Number of primary spikelets (NESP)	13.19 b	16.30 a	12.73 b	16.24 a	14.61	0.723
Peduncle tassel length (LPED) (cm)	20.08 c	19.86 c	23.28 a	21.52 b	21.18	0.655
Length of branched part (LRAM) (cm)	11.57 b	13.52 a	11.04 c	13.48 a	12.41	0.461
Central rachis length (LRC) (cm)	27.13 b	26.69 b	28.08 a	26.89 b	27.20	0.668
LRAM/Tassel length (LESP) (cm)	0.20 b	0.23 a	0.18 c	0.22 a	0.20	0.007
LPED/LESP (LPEDESP (cm)	0.34 b	0.33 c	0.37 a	0.35 b	0.35	0.008
LRC/LESP (LRCLESP) (cm)	0.46 a	0.44 b	0.45 b	0.44 c	0.45	0.009
Number of rows (HIL)	13.08 a	13.09 a	13.36 a	13.34 a	13.21	0.317
Cob diameter (DOLO) (cm)	2.69 a	2.66 a	2.37 c	2.45 b	2.54	0.051
DMAZ/LMAZ (DLMAZ) (cm)	0.34 a	0.31 b	0.30 c	0.31 b	0.32	0.008
DOLO/DMAZ (DOLOMAZ) (cm)	0.60 b	0.61 a	0.56 c	0.56 c	0.58	0.009
Shelling percentage (DESG)	0.81 c	0.80 d	0.83 a	0.82 b	0.82	0.006
EG/AG (EAGRA) (cm)	0.42 c	0.45 c	0.46 a	0.44 b	0.44	0.010
EG/LG (ELGRA) (cm)	0.33 b	0.35 a	0.35 a	0.32 c	0.34	0.009
AG/LG (ALGRA) (cm)	0.79 a	0.79 a	0.75 b	0.74 c	0.77	0.014

† AB1, AB2 = Adaptation to low areas (< 1000 m); AI1, AI2 = Adaptation to intermediate areas (1001 to 1800 m); ¶Values with the same letter in the row are statistically equal (Tukey α=0.05).

The subgroups of low adaptation areas (< 1000 m) were characterized by higher values of DOLO, DLMAZ, DOLOMAZ, ELGRA, and ALGRA. In the case of the subgroups of intermediate areas (AI1 and AI2), they presented populations with higher average values of LPED, LRC, and DESG, and the relationships EAGRA and LPEDESP. That is, these characters distinguish the populations in relation to the pattern associated with the area of adaptation (Figure 1). Differences among subgroups within population groups (low vs. intermediate) are observed with the averages of the characters ASI, AMAZ, NESP, and LRAM, which can be verified with higher values (first quadrant) and vice versa. Populations from altitudes below 1000 m stand out for having higher AF values. These differences, in addition to the intrinsic characteristics of the populations under study and their area of adaptation, are influenced by genetic infiltration, mainly of the Tuxpeño and Tuxpeño Norteño races in the low adaptation area, and in the case of intermediate areas, in addition to these races, the Celaya, Olotillo, Cónico Norteño and Elotes Cónicos races are also involved (Figure 1).

Representative subset

According to the sampling procedure applied from the dendrogram, a subset formed by 13 of the 83 maize populations (15.7 %) was defined, which represents the diversity of the native populations of maize of the Ratón race present in Coahuila. The subset was defined by 8 of 50 (16.0 %) and 5 of 29 (17.0 %) populations from intermediate and low areas, respectively, representing a proportional sampling of the variation (Figure 2).

The populations identified as transition area (> 1800 m) (T2xCN, T61, T1, and T63), located in the dendrogram in subgroup AI1, were not selected for the subset due to the presence of variation associated with the Cónico Norteño race. In a previous study with ear data, Rincón-Sánchez and Ruiz-Torres (2018) applied this methodology and defined a subset of 18 out of 77 populations of native maize (23.4 %), where at least one population of the least represented races was included, which allowed defining a subset that concentrates the types of native maize at the regional level.

The means of some of the morphological characteristics used in the classification of importance in the subset are presented (Table 4).

Table 4. Means of morphological characters of the representative subset of 13 populations of the Ratón race of Coahuila.

	Representative subset populations†												
Characters	I3	I5	I14	I27	B32	I54	B70	I74	I82	B86	B90	B91	I98
Adaptation area	I	I	I	I	B	I	B	I	I	B	B	B	I
Grain type	Sd	Sd	Sd	Sd	Sc	Sd	Sd	Sd	Sd	Sd	Sd	Sd	Sd
Grain color	BC	BC	BC	BC	BC	BC	BC	BC	BC	AC	BC	BC	BC
Male flowering (d)	85.9	84.1	83.5	88.9	69.8	76.0	94.0	75.8	80.6	79.6	84.3	84.1	75.4
Female flowering (d)	88.6	85.5	84.5	90.4	72.1	76.6	98.0	76.8	82.6	81.0	86.8	85.6	76.3
Grain yield (Mg ha^{-1})	5.9	6.2	6.0	6.1	4.5	6.1	5.1	5.1	5.7	5.7	4.4	3.9	5.0
Plant height (cm)	198.9	218.2	213.9	226.8	166.5	190.8	226.8	170.5	193.3	191.4	182.9	190.9	154.8
Leaf length (cm)	91.4	89.2	94.7	95.9	79.3	87.8	92.8	80.9	82.4	90.7	79.8	85.3	74.2
Leaf width (cm)	8.7	8.0	7.9	8.7	7.3	8.1	9.3	8.1	8.3	8.3	8.7	8.0	7.3
Number of leaves above the ear (cm)	5.0	5.5	5.5	5.0	4.3	4.9	5.3	4.9	4.8	4.8	4.9	4.9	3.8
Number of primary spikelets	16.2	15.2	16.2	16.2	14.2	14.9	19.3	15.8	13.7	15.4	12.3	15.8	11.3
Tassel length (cm)	61.5	58.7	61.0	65.0	60.8	64.1	56.5	55.8	58.4	58.7	55.1	57.4	59.2
Number of rows	12.3	13.6	14.0	14.0	12.7	12.7	13.5	14.1	13.9	12.9	13.0	12.1	13.9
Number of grains per row	30.9	29.5	30.1	28.7	23.9	32.0	29.4	31.7	31.3	29.4	29.9	32.2	28.9
Ear length (cm)	14.8	14.5	14.1	13.9	12.2	14.2	13.3	14.0	13.7	13.9	13.7	14.1	13.7
Ear diameter (cm)	4.2	4.4	4.4	4.4	4.5	4.3	4.3	4.3	4.3	4.5	4.3	4.0	3.8
Shelling (%)	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Grain length (cm)	1.1	1.2	1.1	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.2	1.0	1.1
Grain width (cm)	0.9	0.9	0.9	0.8	1.0	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8
Grain thickness (cm)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

† I: Intermediate adaptation; B: low adaptation; Sd: semi-dent; Sc: semi-flint; BC: creamy white; AC: light yellow.

The average results of the representative subset indicate that its vegetative cycle varies from 70 to 94 days, with grain yield ranging from 3.95 to 6.16 t ha^{-1}. Similar results have been reported by Espinosa-Tamayo *et al*. (2019), who pointed out that populations of the Ratón race of Coahuila are early-cycle, with wide adaptation and good yield potential. According to the CONABIO database (CONABIO, 2011), Ratón race populations have a plant height of 238 cm (144–334), growing season of 73 d (55–94), 12 rows (10–16), and 17 to 43 kernels per row; cob length and diameter of 8 to 21 and 3 to 5.6 cm, respectively; kernel dimensions of 1.12, 0.83, and 0.35 cm for length, width, and thickness, respectively. In this study, plant height ranged from 154 to 227 cm, with 4–5 leaves above the ear; length between 70–90 cm, and width between 7–9 cm of average leaf; tassel had lengths between 50 to 60 cm and 11 to 16 primary spikelets.

Ears are distinguished by having an average of 12 rows, 23 to 32 kernels per row, ear length of 12.2 to 14.8 cm, ear diameters of 4–4.5 cm, and a shelling percentage of 0.80 %. And kernel dimensions of 1.1, 0.9, and 0.4 cm for length, width, and thickness, respectively.

The type of grain is semi-dent; dent, with presence of semi-flint; the color is predominantly creamy white, with presence of yellow. The description of the populations of the representative group generally coincides with other studies of diversity of populations of the Ratón race, such as CONABIO (CONABIO, 2011), Rincón-Sánchez and Ruiz-Torres (2015) in populations of Coahuila, and González-Martínez *et al*. (2020) in Tamaulipas.

CONCLUSIONS

The diversity of the Ratón race populations was structured to the adaptation area of low - intermediate - transition areas due to tassel characters (peduncle length, central rachis length), ear characters (cob diameter and ear-grain ratio) and relationships in grain dimensions (length, width, and thickness), and within adaptation areas to plant characters (plant and ear height, and leaf area of the ear leaf) and tassel characters (primary spikelets and length of branched part). A representative subset of the diversity of maize of the Ratón race in Coahuila was defined, consisting of 13 populations (15.7 % of the total evaluated).

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