Article

Ethnogenetic racial patterns of Tabloncillo and Tuxpeño maize, as mechanisms of conservation of native germplasm

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Abstract

The diversity of the native maizes represented by the presence of primary races *per se*, genetic mixtures among them, the plurality of agroecosystems where they are cultivated and the interrelations between them; encourage the presence of ethnogenetic or varietal patterns. The presence of native maize in the State of Nayarit can now be considered broad, since they are found in all the municipalities. The objective of the present work was to know and highlight the importance of the Tabloncillo and Tuxpeño Races as ethnogenetic racial patterns determining the genetic conservation of the native maize of Nayarit. From 2008 to 2012 there were 166 collections, which were agronomically characterized and determined their racial classification. Plant variables (cob and grain) and environment based on their georeferencing were considered. The characteristics of length of cob, grain per row, width and length of grain allowed phenotypically identify the ethnogenetic pattern of Tabloncillo, and the characteristics of cob diameter, number of rows, grain thickness and volume of grain to Tuxpeño. The environmental variables allowed to corroborate the distribution of both ethnogenetic corridors and the location of their respective ecological niches.

Keywords: *Zea mays* L., ethnogenetic patterns, Tabloncillo, Tuxpeño breeds.

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Introduction

Mexico is considered the center of origin and genetic diversity of maize (Sánchez *et al*., 2000). This diversity of corn has manifested itself; through the presence of races, or native varieties, generically denominated as creole maize by the farmer, which has preserved them for its use through its traditional methods of cultivation (Muñoz, 2003).

The creole maize is a term used by farmers to differentiate native maize or adapted to the agro-ecological conditions of their region, from a type of corn obtained through genetic improvement programs. They are commonly heterogeneous, homo-heterozygous populations, developed and conserved by farmers through multiple generations of empirical selection for specific characteristics such as grain texture, color, cob shape, health, vegetative cycle, among others. These native maizes are, primarily, the product of the selection that man has practically made since time immemorial; at the same time, with the intervention of the environment and in terms of ecological pressure, culinary and metaphysical concepts (Hernández, 1970; Rincón *et al*., 2010).

During the process to choose the most desirable characters in the native maize, the woman and the man applied together to carry out the task of selecting the types of plant and cob with better ability to survive in the environment in which they made their cultivation, with women having a decisive influence in selecting the best quality properties in the grain for the different food uses (Ron *et al*., 2006).

This joint dynamic contribution within the traditional cultures of the processes of selection, formation and conservation of these maizes; contributes significantly to the fact that currently available native maize in virtually all states of Mexico. It is known that, in the traditional agricultural systems, especially those prevailing in rainfed crops, the production systems become complex and integral where the cultivation of corn has an important role in the family economy of the communities, whose production is destined mainly for self-consumption and use as fodder (Rincón *et al*., 2010).

The genetic diversity of the native maizes represented by the presence of primary races per se and genetic mixtures between them (varieties with influence of secondary races) and the multiple presence of agroecosystems where they are cultivated and the interrelations between them have allowed to elaborate a racial classification or groups racial. Due to its constant presence through environments Muñoz (2003), it classifies and denominates ethnophitogenic patterns or varietal pattern.

The presence of native maizes in the state of Nayarit today can be considered broad, because they have been located in all the municipalities, through the presence of seven primary races of native maize: Tabloncillo, Tuxpeño, Elotero from Sinaloa, Blando de Sonora, Bofo, Western Elotes and Vandeño; and 11 races with presence of secondary races by influence or genetic infiltration of that second race. The presence of these 11 secondary races, by the movement or exchange of germplasm of native maize between localities within the prevailing agricultural regions of the entity (Regions Sierra, Valles and Costa), which has been maintained through time to the present, has consequently led to the current presence of interracial genetic infiltration.

The importance of the presence of this genetic flow has promoted that this native germplasm continues to cover the needs and conveniences of the rural population and ethnic groups, mainly Huichol, Cora and Tepehuano, who use and conserve these native maizes given their agronomic-food attributes, religious and ceremonial (Vidal *et al*., 2017). The Tabloncillo breed is currently distributed in the North Pacific and Central Pacific states and its potential distribution areas cover the states of Campeche, Yucatan, Oaxaca and Puebla (Ron *et al*., 2006; Ortega *et al*., 2013). The Tuxpeño breed is one of the races with greater distribution and geographical representation in Mexico and therefore with greater adaptability, whose current and potential distribution is very broad (Ruiz *et al*., 2008; Ortega *et al*., 2013).

The great genetic diversity of the native maize prevalent in Nayarit, sustained in large part by the greater presence of the Tabloncillo and Tuxpeño breeds and their genetic combinations in the state, leads to highlight the prevalence and importance of these two breeds as varietal patterns, especially by its presence in places previously not reported, which is also an indication of its feasible presence as genetic corridors in recent times, which have reached interstate ranges. Therefore, the objective of this work was to know and highlight the importance of the Tabloncillo and Tuxpeño Races as ethnogenetic racial patterns determining the genetic conservation of the native maize of Nayarit.

Materials and methods

Study zone

It comprised the entire state of Nayarit, which is located between 23º 05’ and 20º 36’ north latitude and 103 º 43’ and 105º 46’ west longitude. It has an extension of 27 857 km^2, for which it occupies the 23rd place nationally since it represents 1.4% of the total area of the country (INEGI, 2015).

Regionalization and climatic characteristics

Due to its climatic and altitudinal characteristics, the study area was divided into three polygons: Costa Region (composed of the municipalities of Tecuala, Acaponeta, Rosamorada, Ruiz, Tuxpan, Santiago Ixcuintla, San Blas, Compostela and Bahia de Banderas) where a prevailing subhumid warm climate of the Aw type with an annual average temperature higher than 22 ºC and a temperature of the coldest month greater than 18 ºC and an altitudinal range that goes from 0 to 300 meters above sea level. Valles Region (which includes the municipalities of Tepic, Xalisco, Santa Maria del Oro, Jala, San Pedro Lagunillas, Ahuacatlan, Ixtlan del Río and Amatlan de Cañas) with a subhumid semi-warm climate of the type (A)C(w) with an average annual temperature greater than 18 ºC, temperature of the coldest month less than 18 ºC and an altitudinal range from 500 to 1 600 m.

Sierra Region (the municipalities that comprise it are Huajicori, La Yesca and Del Nayar) with a temperate subhumid climate of type C(w) with an annual average temperature between 12 ºC and 18 ºC, the coldest month between -3 ºC and 18 ºC and an altitudinal range between 900 and 1 200 m with one with a drier month precipitation of less than 60 mm, summer rains with precipitation/temperature index between 43.2 and 55.3 and winter rainfall percentage of 5% to 10.2% of the annual total (García, 1964).

Genetic material

Seven primary races of native maize with current prevalence in the State of Nayarit were explored: Tabloncillo (42 collections), Tuxpeño (30), Elotero de Sinaloa (10), Blando de Sonora (3), Western Elotes (4), Bofo (2) and Vandeño (1), and the 11 secondary races or subraces that show influence or genetic infiltration of a second race: Tuxpeño x Tabloncillo (17), Tabloncillo x Tuxpeño (15), Western Elotes x Tabloncillo (2), Tabloncillo x Olotillo (1), Tabloncillo x Blando de Sonora (1), Western Elotes x Elotero de Sinaloa (1), Vandeño x Tabloncillo (3), Reventador x Tabloncillo (3), Olotillo x Tabloncillo (1) and Harinoso de Ocho x Tabloncillo (1).

Sites and number of collections

The harvest period of native maize ranged from 2008 to 2012, in collaboration with the National Plant Genetic Resources System (SINAREFI) of SNICS- SAGARPA, the National Commission for the Knowledge and Use of Biodiversity (CONABIO)-SEMARNAT, Foundation Produce Nayarit, AC and Municipal Presidencies. The prevailing state geographical composition was covered: Valles Region (RV), Sierra Region (RS) and Coast Region (RC), each of the collection sites being georeferenced. In 2008, 68 collections in eight municipalities: Amatlan de Cañas (4) (RV), Ixtlan del Rio (8) (RS and RV), Ahuacatlan (12) (RV), Santa Maria del Oro (9) (RV), Del Nayar (3) (RS), La Yesca (21) (RS), Tecuala (6) (RC) and Acaponeta (5) (RC). During 2010, 42 collections in eight municipalities: Seven in the Coast Region (RC): Banderas Bay (16), Compostela 85), San Blas (2), Santiago Ixcuintla (2), Tuxpan (6), Rosamorada (3) and Tecuala (6). Of the Sierra (RS) Huajicori Region (2) and in 2012, 56 collections made in the municipality of Santiago Ixcuintla (RV and RS). A total of 166 collections were made, most of them performed in RC with 107, RV with 33 and RS with 26 collections. The total number of localities sampled was 58 (Figure 1).

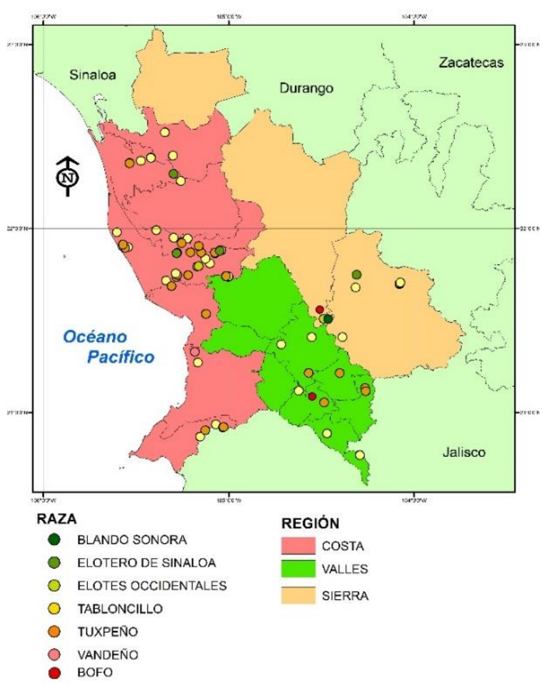

Figure 1. Geographic distribution of the collections, according to primary and secondary races and region in the state of Nayarit.

Collection methodology

In each of the agricultural regions of the state (Costa, Sierra, Valles) were conducted tours for which work groups were organized, the collection periods were based on the harvest and post-harvest periods. The work scheme was based on the methodology and passport sheet suggested by the CONABIO (Ortega *et al*., 2013) through collection routes by municipality, whose collectors gathered direct information from the producer or indirectly from a relative or acquaintance, by location. For the development of this study, the following aspects were considered for the field work and the collection of native corn: a) the number of collections per sampling site, was determined according to the diversity prevailing in the germplasm planted and harvested; by presence of representativeness and inter-racial variation, uses, time of planting by the farmer and variation in the environment in which it was sown; and b) sample size: in each collection, a minimum of 20 and up to 50 cobs of corn representative of the genetic diversity of each native maize existing in the community was programmed; in cases where the producer had already shelled, seed (4.5 kg as sample size) that were included in the present study as grain characteristics was collected. The cobs collected were applied with Deltamethrin (10 ml L^{-1} of water), to eliminate and prevent the infestation of insects that damage the grain, being dried at room temperature until reaching a content of 10% moisture in grain. In most cases a representative sample of uncovered cobs was retained for identification and photography.

Characterization of the collections and taxonomic determination of races

The following concepts were considered in the passport sheet: primary race, secondary race, collector data, date of collection, catalog data, state, municipality, location, georeferencing of the collection site, determinator, name and data of the farmer, characteristics of the sample collected, uses, destination of production, characteristics of the sample collected from cob and gram, as well as agronomic management. Quantitative data were considered based on the morphological characteristics of the total number of cobs reported per collection and a representative and random subsample of grains (n= 5). The taxonomic identification of the maize races found was carried out with the support of participating experts, and based on the available literature (Sánchez *et al*., 2000; Ron *et al*., 2006; Ruiz *et al.*, 2008).

Database

The information on the passport sheet containing the data for the characterization of cobs and grain was protected in an information system for the CONABIO Biotic 4.5 database (Ortega *et al*., 2013). A second database was created generated with the environmental variables prevailing in the collection sites. The final database was constituted by integrating the two previously described.

Plant variables

For the purposes of the present work, only the following variables of cob and grain (in cm and ml) were considered: length of cob (LM), cob diameter (DM), number of rows (NH), number grain per row (GH), grain width (AG), grain length (LG), grain thickness (GG), grain volume (VG).

Environmental variables

The environmental characterization was carried out with the data from the climate information system interpolated by the INIFAP (Ruiz *et al*., 2018) at a resolution of 90 m. The climatic variables obtained from the system for each sampling site were: annual precipitation (PAA), average annual minimum temperature (TIA), average annual maximum temperature (TXA), annual average potential evapotranspiration (ETPA) and annual humidity index (IHA) which is the relationship between precipitation and potential evapotranspiration (PAA/ETPA).

Statistical analysis

A multivariate analysis of main components was carried out from the matrix of correlations between the attributes of cob, grain and the environment. For the selection of the components, the criteria were used: the first two that characterized the variation of at least 80% of the observations and that the typical values were >0.3 (Johnson and Wichern, 2007). To determine the similarity of the races by the geographical origin of the samples, a multivariate cluster analysis was performed for the samples with racial origin Tabloncillo and Tuxpeño (Mohammadi and Prasanna, 2003). The analysis was done with the statistical program Minitab version 17 (State University of Pennsylvania, United States of America).

Results and discussion

Characteristics of cob

With the averages of the selected cob variables (to be used as descriptors and yield components), the collections were subjected to a principal component analysis (CP), the first two components together explained 81.5% of the observed phenotypic variation, where the first component (CP1) with a characteristic value of 1.73, explained, 43.3% of the total variance; the second component (CP2), whose characteristic value was 1.52, referred 38.2%. The variables with the greatest influence in CP1 were cob length (LM) and grains per row (GH). In CP2, the variables with the greatest discriminatory effect were cob diameter (DM) and number of rows (NH) (Table 1).

Table 1. Characteristic vectors, eigenvalues and proportion of the variance explained by the first two main components.

Observed study variables	CP1	CP2
Cob variables		
Length of cob (LM)	0.592*	0.377
Diameter of cob (DM)	0.491	-0.512*
Number of rows (NH)	0.277	0.675*
Grains per row (GH)	0.576*	0.375
Own value	1.7	1.5
Proportional variance (%)	43.3	38.2
Cumulative variance (%)	43.3	81.5
Grain variables		
Grain width (AG)	0.508*	0.071
Grain length (LG)	0.501*	-0.022

Observed study variables	CP1	CP2
Grain thickness (GG)	0.497	0.678*
Grain volume (VG)	-0.495	0.731*
Own value	3.8	0.1
Explained variance (%)	95.3	2.6
Cumulative variance (%)	95.3	97.9
Climatic variables		
Annual rainfall (PAA)	0.519	0.013
Average annual minimum temperature (TIA)	0.508	-0.18
Average annual maximum temperature (TXA)	0.265	-0.758
Average annual potential evapotranspiration (ETPA)	-0.358	-0.614
Annual humidity index (AHI)= PAA/ETPA	0.524	0.125
Own value	3.4	1.3
Explained variance (%)	67.8	25.9
Cumulative variance (%)	67.8	93.7

Based on the dispersion of the 166 collections made through CP1 and CP2, the variables LM and GH were identified as criteria for grouping the primary and secondary races within the ethnogenetic pattern of the Tabloncillo race: similarly, the DM and NH characteristics allowed to identify those primary and secondary races convergent with the ethnogenetic pattern of the Tuxpeño race (Figure 2). This coincides with the descriptors used to characterize these races (Rocandio *et al*., 2014), which identified LM, NH, as appropriate variables for the racial characterization of native maize. The Tabloncillo cobs are identified by having a longer length and consequently more grain per row, while the cobs of the Tuxpeño race, although they are shorter, have a larger diameter and consequently a greater number of rows than Tabloncillo (Ortega *et al*., 2013).

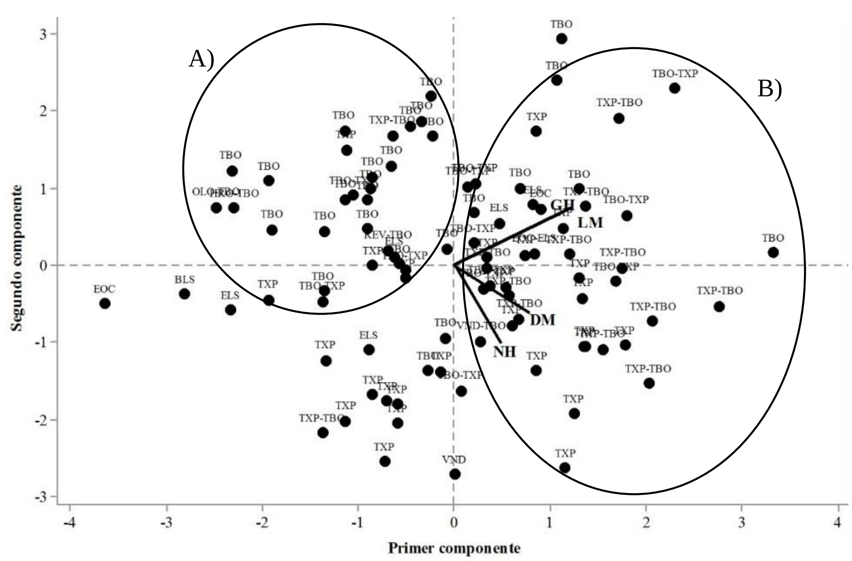

Figure 2. Dispersion of 166 maize collections made in Nayarit, based on the first two main components, on cob characteristics. A) Tabloncillo group; and B) Tuxpeño group.

Grain characteristics

The first two main components with the averages of the grain variables selected, explained 97.9% of the phenotypic variation observed, where the first component (CP1) with a characteristic value of 3.81, explained 95.3% of the total variance and the second component (CP2), whose characteristic value was 0.1, showed 2.6%. Of the grain variables analyzed, the original variables with the greatest influence in CP1 were grain width (AG) and grain length (LG), while in CP2 the original variables of greater importance were grain thickness (GG) and grain volume (VG).

As the variables, AG and LG used as criteria of grouping of all the explored genetic material, they allowed to identify the primary and secondary races grouped within the ethnogenetic pattern of the Tabloncillo race; based on said grain characteristics. In the same way, the characteristic VG allowed to identify those primary and secondary races convergent with the ethnogenetic pattern of the Tuxpeño race, while the grain thickness (GG) was located in both varietal patterns (Figure 3). Rocandio *et al.* (2014) when describing seven maize races of High Valley, when making their AG morphological and agronomic identification, they mentioned LG, GG as appropriate variables to carry out their racial description. Similarly, Rincón *et al*. (2010) when studying the diversity and distribution of native maize, they use grain characteristics as descriptors of racial identity.

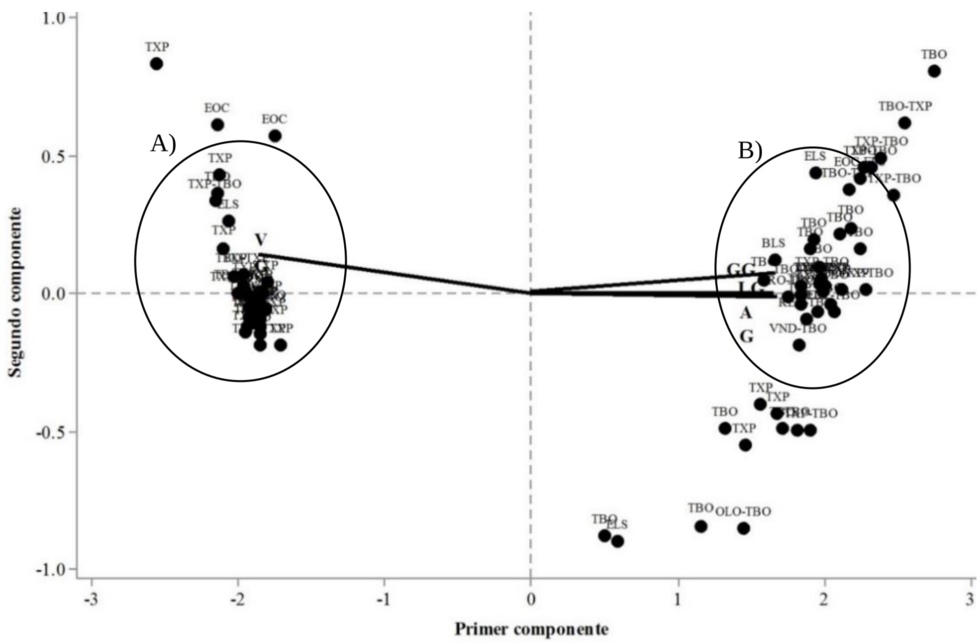

Figure 3. Dispersion of 166 maize collections in Nayarit, based on the first two main components, on grain characteristics. A) Tuxpeño group; and B) Tabloncillo group.

Environmental variables

With the five environmental variables selected, the racial genotypes were subjected to the principal component analysis (CP). The first two components explained 67.8 and 25.9% of the total variation, respectively and an accumulated variance of 93.7%. In CP1 the annual precipitation

(PAA), the minimum annual average temperature (TIA) and the annual humidity index (IHA); contributed mostly to the variation explained by this component. Similarly, in CP2, the most important characteristics were the mean annual maximum temperature (TXA), and the annual mean potential evapotranspiration (ETPA) (Table 1). In this way, the IHA and PAA variables were the criteria for grouping the primary and secondary races within the ethnogenetic pattern of the Tabloncillo race. The ETPA characteristic allowed to identify those primary and secondary races convergent with the ethnogenetic pattern of the Tuxpeño race, while the grain thickness was located in both varietal patterns (Figure 4). From the above, it is inferred that the environmental conditions where the Tabloncillo varietal pattern prevails, due to its early and intermediate vegetative cycle, archetype of lower leaf density and low-intermediate size are more dependent on the available humidity (PAA and IHA) than on the temperature (Ron *et al*., 2006; Ruiz *et al.*, 2008).

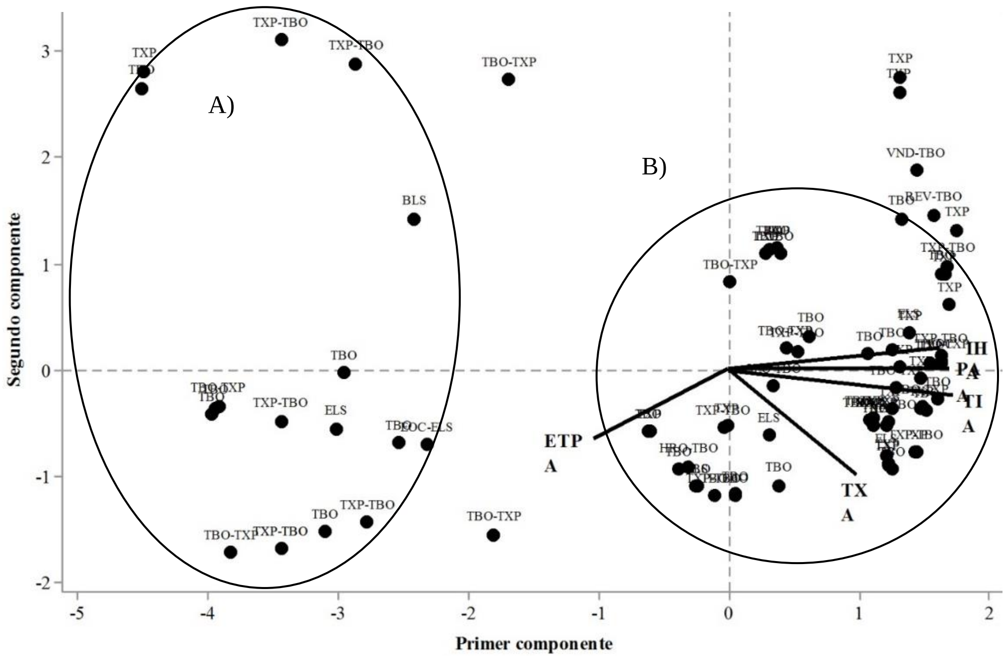

Figure 4. Dispersion of 138 maize collections carried out in Nayarit, based on the first two main components, on climatic characteristics. A) Tuxpeño group; and B) Tabloncillo group.

The Tuxpeño varietal pattern, due to having a late vegetative cycle, archetype of abundant leaf density and tall size, have higher thermoenergetic requirements (TXA) and consequently require higher potential evapotranspiration (ETPA) (Ruiz *et al*., 2008). The previous, also in consequence, is reflected in a greater yield of grain in the Tuxpeño race (2.9 t ha^{-1}) than in the Tabloncillo (2.5 t ha^{-1}) (Vázquez, *et al*., 2003).

The wide distribution of the ethnogenetic patterns of Tabloncillo and Tuxpeño is widely supported by the presence of ecophysiological indicators in the different maize races, which show that this species currently has a wide range of responses to the environment, which promotes an inter-racial variation significant, that validates the influence of climate diversity on the cultivation of corn and are a sample of the genotype-environment interaction that has been occurring from the dispersion of corn throughout the Mexican territory (Ruiz *et al*., 2013).

Ecological niches of ethnogenetic patterns Tabloncillo and Tuxpeño

The great capacity of response that the races have to the diversity of the environments where they are cultivated (Ruiz *et al*., 2008) have favored the proliferation of ecological niches possessing an environmental potential (Muñoz, 2003). The favorable environmental conditions prevailing in Nayarit, over time have allowed the potential distribution of the Tabloncillo and Tuxpeño maize races and their genetic combinations as secondary races, to become current distribution (Ruiz *et al*., 2013).

In this way, Tabloncillo was found in the ethnogenetic pattern, at least the presence of four ecological niches given its greater environmental similarity: Niche 1: Acaponeta - Rosamorada and Niche; 2: Ruiz-Tecuala because both are located in the coastal region of the state. Niche 3: San Pedro Lagunillas-Tepic-Jalisco-Santiago Ixcuintla, and Niche; and 4: Ixtlan-Santa Maria del Oro, for its location within the Valles and Sierra regions (Figure 5 A). For the ethnogenetic pattern Tuxpeño, the ecological niches determined in the present study were three, which presented a greater amplitude of distribution Niche 1: Ixtlan del Río-Rosamorada-Ahuacatlan-Santa María del Oro, in the Sierra and Valles regions; Niche; 2: Ruiz-Santiago Ixcuintla-La Yesca, in the Sierra region; Niche; and 3: from Nayar-Jala-San Pedro Lagunillas-Tecuala-Tepic-Xalisco-San Blas, with greater presence in the Valles region, followed by the Costa and Sierra region (Figure 5 B).

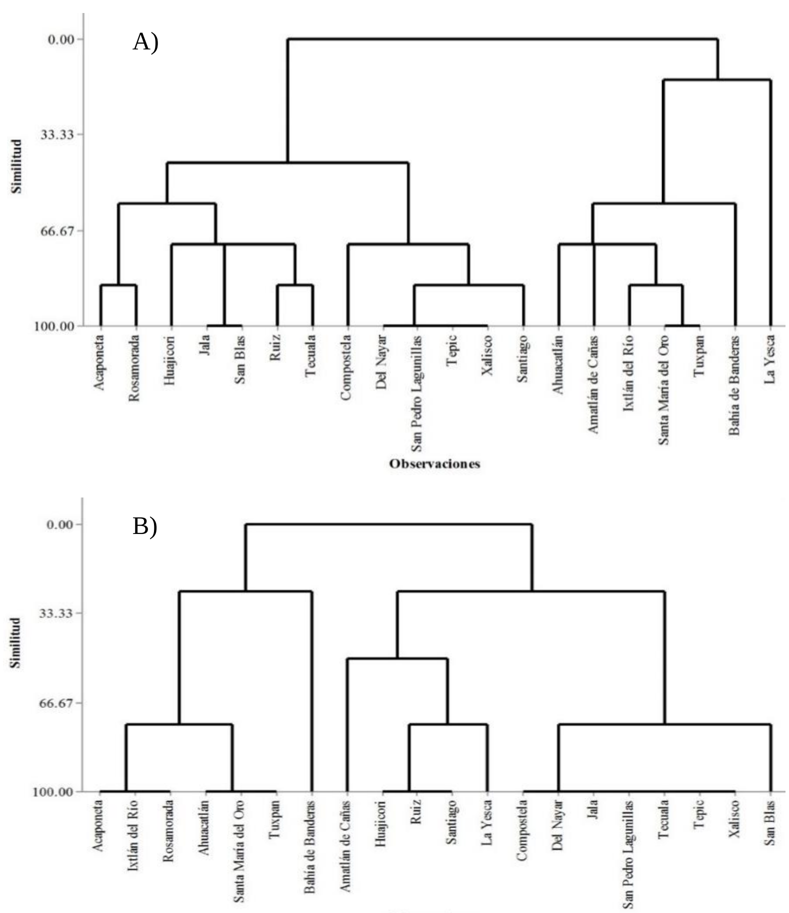

Figure 5. Dendrograms of the state distribution of ethnogenetic patterns of races A) Tabloncillo (TBO); and B) Tuxpeño (TXP).

This can be attributed to the fact that the great distribution of the agroclimatic conditions where corn is grown has led this species, through acclimation and adaptation processes, to express its genetic and phenotypic plasticity, above all due to the presence of natural and induced hybridization; which has led to a greater presence of interracial genetic diversity through environments (Ruiz *et al*., 2013).

Thus, the highest prevalence of four ecological niches within the Tabloncillo ethnological pattern, indicated the presence of genetic flows between the breed Tuxpeño, Elotes Occidentales, Elotero de Sinaloa, Olotillo, Vandeño, Blando de Sonora and Harinoso de Ocho and Vandeño. Within the Tuxpeño varietal pattern, its genetic infiltration with Tabloncillo predominated.

This movement of germplasm has allowed the permanence and existence of these races through interracial genetic infiltration through the regions where the native maize is cultivated. This genetic flow can be attributed to the absence of gametophytic incompatibility in the Tabloncillo and Tuxpeño breeds because they are recessive homozygotes in the presence of alleles of incompatibility (Padilla *et al*., 2012).

This has allowed the native germplasm to continue covering mainly the needs of the ethnic groups and rural population that continue using and conserving these native maizes for their agronomic-food attributes (Hernández, 1970; Muñoz, 2003; Ron *et al*., 2006; Rincón *et al*., 2010; Vidal *et al*., 2017).

Conclusions

The Tabloncillo and Tuxpeño Races were identified as ethnogenetic racial patterns determining the genetic conservation of the native maize of Nayarit, both for its distribution *per se*, and for its genetic infiltration in a second race: Tabloncillo x Tuxpeño, Tuxpeño x Tabloncillo, Western Elotes x Tabloncillo, Tabloncillo x Olotillo, Tabloncillo x Blando de Sonora, Elotes Occidentales x Elotero de Sinaloa, Vandeño x Tabloncillo, Reventador x Tabloncillo, Tabloncillo Ahumado x Tuxpeño, Olotillo x Tabloncillo and Harinoso de Ocho x Tabloncillo.

The characteristics of length of cob, grain per row, width and length of grain allowed phenotypically to identify the ethnogenetic pattern of Tabloncillo and the characteristics of cob diameter, number of rows, grain thickness and volume of grain to Tuxpeño.

The environmental variables allowed to corroborate the distribution of both ethnogenetic corridors and the location of four ecological niches in the Tabloncillo varietal pattern and four in the Tuxpeño one.

Acknowledgments

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