Variability in Cornhusk Traits of Landraces from the State of Puebla, Mexico

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ABSTRACT

Maize (*Zea mays* L.) germplasm accessions in Mexico have been studied for grain yield and other traits. The cornhusk, or totomoxtle, is more important than the grain for Mexican peasant farmers because it generates increased income. However, limited information is available on the level of phenotypic variation in cornhusk traits, and few studies have been performed on the potential of maize landraces for the production of cornhusk. This study assessed maize landraces from three regions in Mexico. These landraces (as well as checks) were evaluated at multiple locations using lattice designs. The measured variables included the per-plant grain yield, cornhusk length and width, ear coverage, and cornhusk, peduncle and ear weight. A cluster analysis of the data from the three regions grouped populations according to their region of origin. Morphological diversity within the cornhusk traits among maize landraces was found in the three regions, and landraces from Tehuacan had the greatest potential for cornhusk production. The measured cornhusk traits were superior in the maize landraces compared with those of the improved hybrids. The cornhusk weight, length and width, and ear coverage were the most effective traits for grouping according to population origin and discriminating among the populations. Thus, these traits are proposed as phenotypic selection criteria for identifying promising maize populations and initiating breeding programs for improved cornhusk production.

Mexico is the center of origin, domestication, and dispersion of maize. Fifty-nine landraces have been described in the country (Ortega, 2003; Kato et al., 2009), and they account for 22.7% of the diversity described for the American continent, where approximately 300 different landraces have been reported (Serratos, 2009). The high levels of genetic variability in maize have enabled its adaptation to a wide range of altitudes, from sea level to more than 3000 m, as well as to the multitude of ecological niches that occur in Mexico. According to Herrera et al. (2000), a significant fraction of this diversity occurs in regions where rainfed conditions and traditional production systems prevail.

Gil et al. (2004) noted that during maize domestication and breeding in Mexico, humans shaped the species to suit both their food and cultural requirements. Because of this human intervention, maize has become an essential element in the structure, consistency, and sustainability of ancient and contemporary Mexico as well as a central component of the diet (Muñoz, 2005). A larger number of traditional uses for maize are found in rural areas. These uses extend beyond food, for which both dry grain and tender corn are used. Other applications include (a) livestock fodder (grain, ears, leaves, stems, tassel, and cornhusks), (b) compost (leaves, stems, roots, and cobs), (c) medicine (ear silks), (d) wrapping (cornhusks and leaves) and handcrafts (cornhusks and stem), (e) fuel (cob), and (f) ceremonial uses (grain, ear and plant). It is important to note that in Mexico, native maize populations are preferred over improved varieties (Gil and Álvarez, 2007).

Because of the described use patterns, there are two major domains in the native gene pool: one domain for traits related to food uses and another domain for adaptive traits (Muñoz, 2005). The study, conservation, and use of both domains of native genes have become issues of vital importance.

Puebla is one of the most important Mexican states in terms of maize diversity and history. The most significant archaeological evidence of the antiquity of agriculture and domestication of maize originate from the Tehuacan Valley (MacNeish, 1995). Gil et al. (2004) assessed the diversity and agronomic potential of maize landraces in 15 subregions of Puebla and found a large number of native populations (2514 accessions were collected) associated with broad phenotypic diversity. In addition, these authors found considerable variability in grain color, maturity, and agronomic characteristics in every ecological niche. Their findings were mainly associated with variations in production environments and, to a lesser extent, the diversity of traditional uses of the species.

The heterogeneity of the environments in which plants are grown is one of the major factors involved in the generation of diversity (García et al., 1989; Linhart and Grant, 1996). Factors

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that have contributed significantly to the variability of maize include farmer selection to deal with the different hygrothermal and environmental regimes that occur in the niches of the agricultural areas (Muñoz, 2005) and seed exchange among farmers (Badstue et al., 2006, 2007). A greater amount of attention has been paid to breeding for attributes that are related to grain yield (Herrera et al., 2002), whereas farmer selection practices have focused heavily on ear characteristics (Louette and Smale, 2000).

The considerable amount of genetic variation in the attributes related to grain suitability for different traditional uses has been documented (Mauricio et al., 2004; Rangel et al., 2004). However, the market demand in recent years for maize-derived products, such as cornhusks, has resulted in a change in the selection criteria in certain regions to include the potential for abundant cornhusk production (cornhusks, or totomoxtle, are the outer bracts that enclose the ear). Typical examples are cultivar Jala maize in the state of Nayarit, Mexico (Rice, 2006), and landraces from the Totonaca area (King, 2007) in the state of Veracruz, Mexico. In both cases, a remarkable feature is that native maize populations have higher-quality ear coverage and cornhusk yield than do the improved maize hybrids.

In addition to contributing photosynthates to developing kernels (Kang et al., 1986) and protecting ears from insect damage in the field (Demissie et al., 2008), cornhusks are used in a variety of ways. Cornhusks are a crucial ingredient in the preparation of tamales (Long and Villarreal, 1998). The word tamal comes from the Nahuatl "tamalli" and refers to maize dough that is wrapped in banana or maize leaves or cornhusks (totomoxtle) and steamed or oven cooked (Antonio et al., 2004). Cornhusks are also used as a raw material for the production of handcrafts (dolls, flowers, replicas of animals, etc.), fashioned into strips to tie bundles of herbs, spices and wild plants, and used in the production of handmade cigarettes (Long and Villarreal, 1998). Moreover, the structure and properties of cornhusk fibers, which are similar to cellulose fibers isolated from cotton and linen, are of sufficient quality for textile and industrial applications. Thus, cornhusk fibers have the potential for use as an inexpensive natural cellulose fibers in textile applications (Reddy and Yang, 2005a, 2005b).

The demand for cornhusks and their derived products has increased in recent years in the domestic Mexican market and international markets, which export primarily to the United States. In several states of Mexico, such as Jalisco, Colima, Nayarit, Michoacán, Oaxaca, and Tamaulipas (Long and Villarreal, 1998), as well as the Totonac region of Veracruz (King, 2006), farmers have oriented their market activities toward producing cornhusks with native materials because these materials have superior characteristics for cornhusk processing. Marketing cornhusks helps to alleviate rural poverty and promotes the use and conservation of local maize genetic diversity, although the selection of these varieties is only for their potential to produce cornhusks rather than grain (King, 2007).

In Puebla, the use of cornhusks varies by region. In the Puebla Valley, 72% of the households that produce maize sell between 70 and 100% of the total cornhusk production at the local markets. These households have the smallest areas for planting maize, limited livestock activity, comparatively larger families, and lower incomes than other households (Viveros et al., 2010). The farmers here grow maize primarily for cornhusk production in both the humid tropic (Sierra et al., 2010) and Tehuacan Valley regions. Production in the latter region has not yet been documented.

The importance of maize production in Puebla is evident in the levels of production, with the region ranking third nationwide in terms of harvested area under rainfed conditions (528,463 ha) and seventh in the production of grain (837,791 t) (SIAP, 2012).

Limited information is available on the genetic variation among or within native maize populations for cornhusk-related traits. This study was conducted to assess the magnitude of the variability in quality and production potential of cornhusk in the agricultural areas of the state of Puebla.

MATERIALS AND METHODS

Regions of Study

Maize landraces were collected in the Teziutlan, Libres, and Tehuacan regions of Puebla, Mexico (Fig. 1). The characteristics of the study regions are shown in Table 1.

Genetic Material

Maize accessions were collected in the Teziutlan, Tehuacan, and Libres regions as described below. All of the municipalities and main towns were located on an orographic map of each region, and the towns representing the four cardinal points and center of each municipality were selected. The collection routes were then designed and a minimum of three farmers per collection site were visited. These farmers were informed of the purpose of the study, and a seed sample of each of the planted maize types was requested. After collection, a general inventory was performed. Accessions that represented all of the collection sites for which at least 1 kg seed was available were evaluated (Gil and Álvarez, 2007; Hortelano et al., 2012). Samples of the accessions were deposited at the National Vegetable Germplasm Bank, Chapingo Autonomous University, which is located in Mexico State. Table 2 lists information related to the collected genetic material.

For Teziutlan and Libres, the collections were conducted in 2007, whereas in Tehuacan, the collections were conducted in 2009. The collections in Teziutlan were restricted to locations above 1800 m, whereas in Tehuacan, they were restricted to locations above 1500 m. In all three regions, evaluations were conducted during the spring–summer 2009 season. In the Teziutlan region, 76 native materials were assessed, with three landraces (Conico, Chalqueño, and Tuxpeño) and two experimental varieties (Zaragoza Intermedio and Zaragoza Tardío) used as checks. In the Libres region, 135 local materials were assessed against seven landrace checks (two accessions of Conico and Chalqueño and one accession of each of the following: Chalco Palomo, Palomero Toluqueño, and Conico Norteño) and two commercial checks (ASPROS AS722 and Sintético Serdan). In the Tehuacan region, the evaluation involved 95 native materials, with three landrace checks (Bolita, Celaya, and Pepitilla) and two hybrid checks (ASGROW A7573 and ASPROS AS900). The landraces were provided as local checks by the farmers of each region during germplasm collection.

Experimental Sites

In the Teziutlan region, the evaluations were conducted in Taltzintan (19°47′ N, 97°24′ W, 2180 m) and Las Trancas (19°43′ N, 97°34′ W, 2397 m), and the planting dates were 21 Mar. and 18 Apr. 2009, respectively. In the Libres

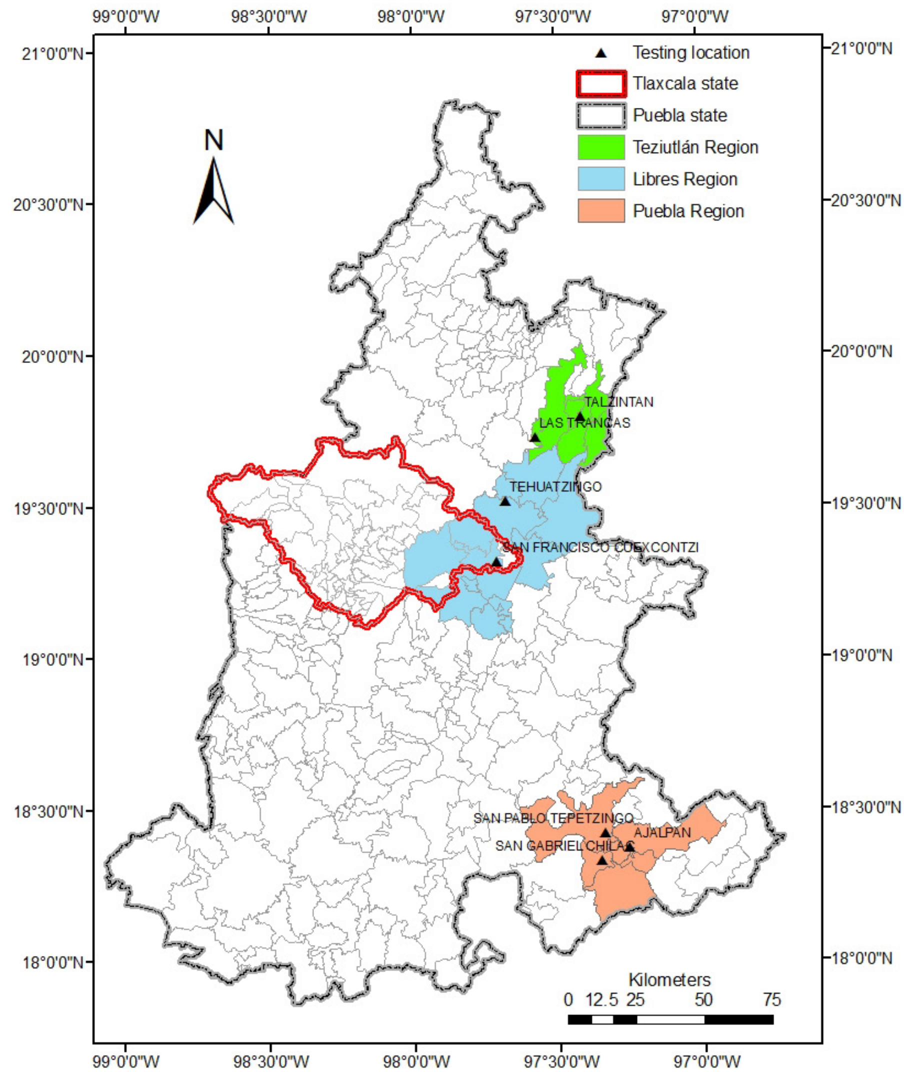

Fig. 1. Location of the study regions and evaluation sites in the Puebla state, Mexico.

region, the collections were planted at Tehuatzingo, Puebla (19°27′ N, 97°41′ W, 2426 m) and Cuexcontzi, Tlaxcala (19°18′ N, 97°46′ W, 2420 m) on 22 May 2009. In the Tehuacan region, the evaluations were conducted at San Gabriel Chilac (18°14′ N, 97°19′ W, 1217 m), San Pablo Tepetzingo (18°28′ N, 97°24′ W, 1410 m), and Ajalpan (18°23′ N, 97°15′ W, 1200 m) (INEGI, 2010) on 8 Aug., 22 June, and 9 July 2009, respectively. Square lattice designs (Cochran and Cox, 1992) were used for the Libres (12 by 12), Tehuacan (10 by 10) and Teziutlan (9 by 9) regions, with two replications. The experimental unit consisted of two 5 m long rows spaced 0.85 m. In each plot, sowing was performed manually with a shovel, three seeds were planted every 50 cm, and hills were thinned to two plants 6 wk after planting. The standard crop management practices of each region were adopted, and fertilizer recommendations of the National Institute of Agriculture, Livestock and Forestry Research (INIFAP) were followed in all of the regions. In the Libres and Teziutlan regions, the experiments were conducted under rainfed conditions, whereas in Tehuacan, they were conducted under irrigation.

Measured Traits

At harvest, five ears (all covered with husk) were collected from an equal number of plants with full competition representative of the visual phenotypic variation within each experimental unit. Several measurements were performed on each ear covered by husk. The ear coverage (cm) was the distance between the apex of the ear and tip of the husk (the husk tip extends above the ear). The cornhusk length (cm) was measured as the distance between the husk base and apex of the ear, and the cornhusk width (cm) was measured in the lower third of the first outer husk that completely covered the ear. The weight of the cornhusk, peduncle, and ear (g) was also recorded. The ears were dried until a constant weight, and the grain moisture was calculated as the difference between the fresh weight and dry weight divided by the fresh weight multiplied by 100. The ears were shelled, and the grain and cob weights were recorded. The shelling percentage was estimated as the ratio of the grain weight of the five ears divided by their total weight (grain plus cobs) and multiplied by 100 (Hernández-Guzmán, 2007). To estimate the grain yield per plant, the fresh weight of the ear was adjusted by the shelling percentage and 140 g kg^{-1} grain moisture and expressed in grams per plant.

Statistical Analysis

Field trials in each location and region were conducted using lattice designs. However, combined ANOVAs were performed for the seven variables and each region based on the incomplete

Table 1. Environmental and physical characteristics of the study regions in the state of Puebla, Mexico.

Main descriptors	Region: Teziutlan	Libres	Tehuacan
Municipalities	Atempan, Chignautla, Teteles de Avila Castillo, Teziutlan, Tlatlauquitepec, Xiutetelco, Zaragoza	Cuyoaco, Tepeyahualco, Ocotepec, Libres, Oriental, San Jose Chiapa, Rafael Lara Grajales, Mazapiltepec de Juarez, Soltepec, Nopalucan; Altzayanca†, Cuapiaxtla†, Huamantla†	Ajalpan, Altepexi, Tehuacan, San Gabriel Chilac, San Jose Miahuatlan, and Zinacatepec
Geographic coordinates‡	19°37′ to 20°03′ N 97°37′ to 97°18′ W	19°04′ to 19°43′ N 98°02′ to 97°20′ W	18°20′ to 18°37′ N 96°56′ to 97°38′ W
Altitude, m‡	300–3200	2300–4400	800–2900
Temperature, °C‡	10–24	10–16	14–24
Precipitation, mm‡	500–4100	300–1100	300–3100
Main climate type‡	Temperate and humid, with abundant rainfall in summer.	Temperate and subhumid, with summer rain of lower humidity.	Dry, very warm, and warm.

† These municipalities belong to the Tlaxcala state, Mexico.
‡ Source: INEGI (2010).

block design model using the PROC GLM procedure of the Statistical Analysis System (SAS) version 8.0 for Windows (SAS Institute, 2008), with the populations included as fixed effects. For the multivariate analysis, only variables associated with cornhusk production were included. Additionally, the landrace checks were not included when comparing the landraces and improved populations in each region because certain checks were not well adapted to that region. For each variable, the averages across the localities were calculated for the populations, and the standardized Euclidean distance matrices were obtained using the PROC DISTANCE procedure of SAS. A cluster analysis was performed using the Euclidean matrices with PROC CLUSTER in SAS. The clustering patterns were visualized by means of a dendrogram as displayed by the PROC TREE procedure

Table 2. Municipalities, number of collecting locations by municipality, grain color of the accessions, and major landraces in the study regions of the Puebla state, Mexico.

Region	Municipaly	Number of collecting locations	Grain color of the accessions: White	Yellow	Blue	Red	Major landraces in the region
Teziutlan	Atempan	7	9	5	2	1	Arrocillo, Cónico, and Elotes Cónicos
	Chignautla	6	9	3	2	1	
	Teteles	1	–	1	1	–	
	Teziutlán	1	1	1	–	–	
	Tlatlauquitepec	3	5	1	2	1	
	Xiutetelco	8	16	3	–	–	
	Zaragoza	4	7	3	2	–	
Libres	Cuyoaco	6	16	10	8	–	Arrocillo, Chalqueño, Cónico, Elotes Cónicos, and Elotes Chalqueños
	Libres	3	5	1	2	–	
	Ocotepec	1	1	–	–	–	
	Oriental	3	6	4	3	1	
	Tepeyahualco	3	7	3	2	–	
	Mazapiltepec	1	2	–	1	–	
	Nopalucan	3	7	1	4	–	
	Rafael Lara Grajales	1	2	–	1	–	
	San José Chiapa	2	3	1	2	–	
	Soltepec	2	3	1	1	–	
	Citlaltépetl	1	4	1	1		
	Altzayanca†	2	5	1	2	–	
	Cuapiaxtla†	1	3	1	1	–	
	Huamantla†	5	12	2	3	1	
Tehuacan	Ajalpan	13	8	–	4	1	Bolita, Celaya, Pepitilla, Tuxpeño, and Vandeño
	Altepexi	10	4	–	6	–	
	Tehuacán	7	18	–	16	3	
	San Gabriel Chilác	8	6	–	–	2	
	San José Miahuatlán	9	9	–	–	–	
	San Sebastián Zinacatepec	16					

† These municipalities belong to the Tlaxcala state, Mexico.

of SAS. Ward's Minimum Variance Method was used to group the populations. To improve the presentation of the graph, the coefficient of determination was used as the scale of dissimilarity between the clusters (Mohammadi and Prasanna, 2003).

RESULTS

The combined ANOVAs revealed variation among the populations for all of the traits (Table 3). The interaction between populations and locations was not significant for two traits for Teziutlan, three traits for Libres, and five traits for Tehuacan. The one common trait that did not show interaction in any region was cornhusk length. On the other hand, grain yield per plant showed significant interaction in all regions.

Figure 2 shows the dendrogram obtained from the cluster analysis. By cutting off the dendrogram at a distance of 0.65 units, four groups were formed by region of origin. In Group 1 populations, approximately 99% were from the Tehuacan region, whereas in Group 2 populations, approximately 70% were from the Teziutlan region and 30% were from the Libres region. In Group 3 populations, 80% were from the Teziutlan region and 20% were from the Libres region. In Group 4, the population was exclusively from the Libres region. This clustering pattern suggests that cornhusk traits are highly conserved in populations within regions. The maize populations from the Teziutlan and Libres regions were more similar, whereas the populations from the Tehuacan region formed a group that was completely separated from the populations of the Teziutlan and Libres regions.

Table 4 shows a comparison of the means of measured traits for the groups that were identified in Fig. 2. The variables that most differentiated the groups were the length and width of the cornhusk and the weight of the cornhusk, ear, and peduncle. Group 1 (which consisted of populations from the Tehuacan region) had the highest averages for cornhusk length, width, and weight as well as ear and peduncle weight and grain yield per plant. This group was followed by Group 3, which consisted of populations from the Teziutlan region, Group 4, which consisted of populations from the Libres region, and Group 2, which had the lowest averages for cornhusk length, width, and weight; and ear and peduncle weight. These results indicated that the genetic materials with the greatest potential for cornhusk production are in the Tehuacan region. Therefore, this region was focused on in subsequent analyses.

Figure 3 shows a dendrogram of the populations that were evaluated in the Tehuacan region. When the dendrogram was cut off at the level of 0.45 units, three groups were identified. Group 1 contained five populations, two of which were the commercial checks A7573 and AS900, which had the lowest averages for cornhusk length, width, and yield and yield per plant but exhibited the highest average ear coverage (Table 5). Group 2 contained 29 populations and included populations with intermediate averages for the different measured traits. Group 3

Table 3. Mean squares from the combined analysis of variance, trait means, and coefficient of variation by region, for seven morphological traits in maize populations evaluated in three regions of the State of Puebla, Mexico.

Trait	Populations	Locations	Populations × locations†	Error	Average	CV
						%
Teziutlan						
Cornhusk length	14.71**	0.21ns‡	4.96ns	5.33	16.59	13.91
Cornhusk width	5.30**	11.23*	3.85 **	2.16	15.87	9.26
Ear coverage	4.75**	7.09 ns	3.61**	2.12	7.11	20.49
Cornhusk weight	188.49**	5136.57**	92.31*	60.58	16.92	46.02
Ear weight	1349.48**	30024.87**	871.57 *	627.78	103.66	24.17
Peduncle weight	17.52**	340.84**	8.32ns	8.33	4.20	68.59
Grain yield per plant	767.50**	63407.15 **	729.37 **	407.86	65.26	30.94
	80§	1§	79§	141§		
Libres						
Cornhusk length	8.06**	1366.01**	2.66ns	2.59	17.20	9.35
Cornhusk width	6.12**	1579.16**	2.69*	2.05	17.13	8.35
Ear coverage	3.94**	82.50**	2.97 ns	2.48	5.27	29.90
Cornhusk weight	71.71**	17109.18**	27.44ns	25.21	16.55	30.32
Ear weight	2644.13**	1712514.65**	1264.69 **	866.10	127.47	23.08
Peduncle weight	8.79**	3829.23**	7.30**	4.49	4.43	47.75
Grain yield per plant	899.18 **	389682.86 **	801.14*	606.90	62.84	39.19
	143§	1§	143§	264§		
Tehuacan						
Cornhusk length	8.75**	198.65**	3.40ns	3.05	20.50	8.52
Cornhusk width	16.49**	18.41**	4.02ns	3.75	21.58	8.97
Ear coverage	4.71**	128.32**	2.56ns	2.69	6.35	25.85
Cornhusk weight	367.24**	2557.88**	148.99**	106.13	38.71	26.60
Ear weight	11168.30**	14088.18**	3333.48ns	2906.42	196.43	27.44
Peduncle weight	29.88**	349.80**	17.38ns	14.51	8.87	42.94
Grain yield per plant	7169.75**	38818.15**	3218.42**	2170.50	135.57	34.36
	99§	2§	196§	267§		

* $P \leq 0.05$.

** $P \leq 0.01$.

† The interaction term "Populations × Location" refers to locations within regions.

‡ ns, no significant at $P \leq 0.05$.

§ Degrees of freedom.

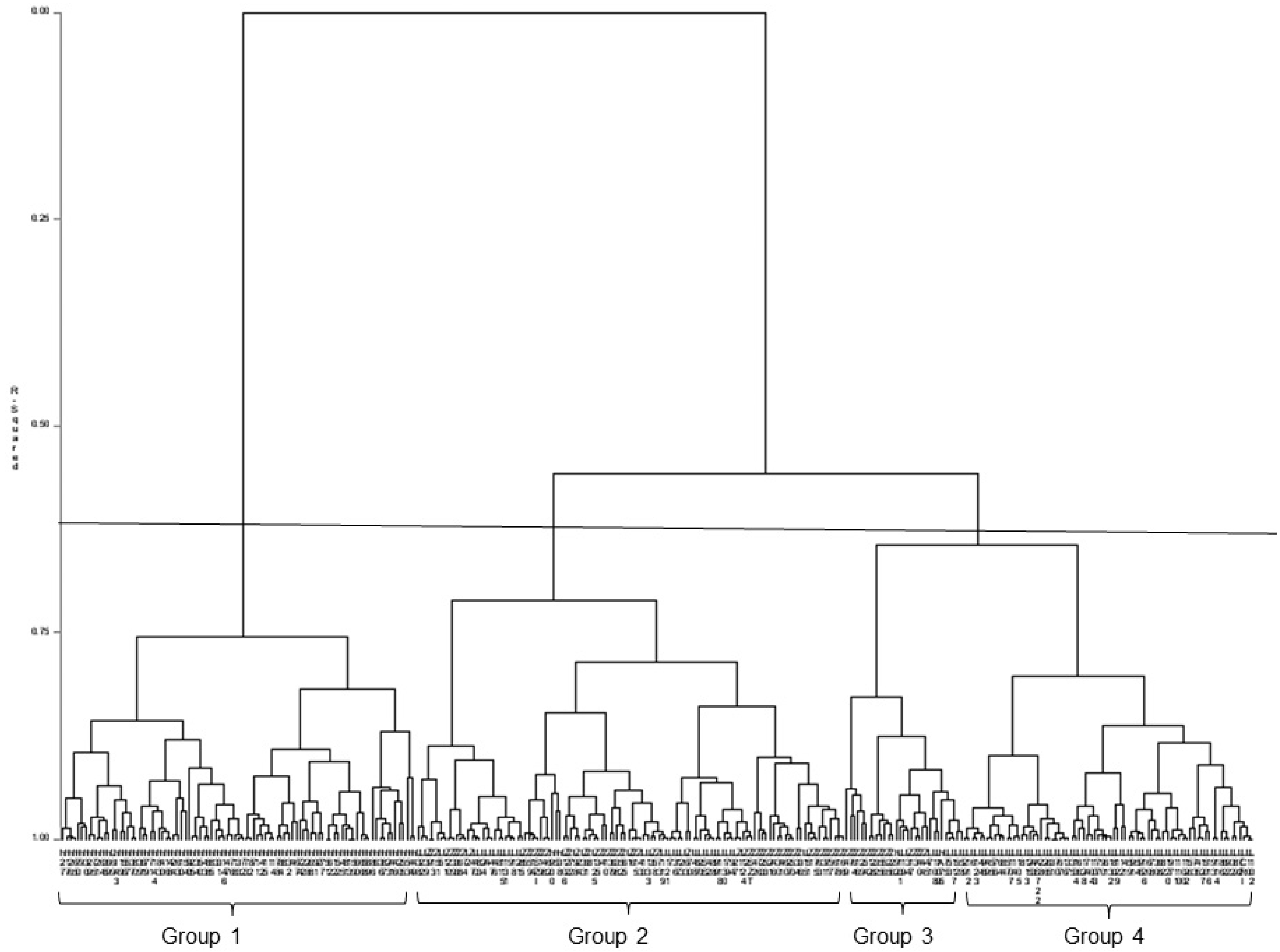

Fig. 2. Dendrogram obtained with Ward's method, using six cornhusk morphological traits measured in maize populations from the Teziutlan, Libres, and Tehuacan regions of the Puebla state, Mexico.

contained 62 native populations and had the highest averages for cornhusk length, width, and weight; and ear coverage, peduncle weight, and grain yield per plant (Table 5). An examination of the group composition revealed that pigmented materials (59% of the total) predominated in Group 2, whereas white grain populations were dominant in Group 3 (71% of the total).

DISCUSSION

Significant differences were observed among the populations for the measured cornhusk traits and within the clustering patterns in Fig. 2, which indicate substantial genetic diversity for these traits in maize populations originating from the three regions of the state of Puebla. This finding is important because it reveals that the variation among native populations (landraces) exceeds what has been reported for the agronomic (Muñoz, 2005) and morphological traits used in characterization studies (Ángeles-Gaspar et al., 2010). These results also confirm the findings of Gil et al. (2004), who reported that a portion of the diversity detected in native maize from Puebla was associated with the traditional uses of the species. As previously stated, this diversity is not random (as shown in Fig. 2); rather, it follows well-defined patterns. In our case is geographical in its origin. This pattern of expression within cornhusk traits reveals close relationships among these traits within each ecological niche or micro-region of origin of the populations, which was proposed and corroborated by Muñoz (2005). These results also confirm that varietal patterns occur in maize, and these patterns are defined as the system that assembles groups of populations (components), strata or environmental levels in which they are grown, and relationships between groups of populations and their environments (Gil, 2011).

Table 4. Means for morphological traits for groups defined in the dendrogram of maize populations evaluated in three study regions of the Puebla state, Mexico.

Group	N†	Cornhusk length	Cornhusk width	Ear coverage	Cornhusk weight	Ear weight	Peduncle weight	Grain yield per plant
		cm			g			
1	93	20.67a‡	21.94a	6.24b	39.64a	204.50a	9.14a	142.89a
2	112	16.03d	15.94d	6.24b	14.17d	99.31d	3.51d	59.77c
3	31	19.24b	17.23c	7.67a	24.17b	130.45c	6.07b	65.52cb
4	76	17.73c	17.91b	4.97c	18.26c	144.43b	5.06c	70.08b

† N, number of populations.

‡ Means with the same letter in columns are statistically equal (Tukey, $P \leq 0.05$).

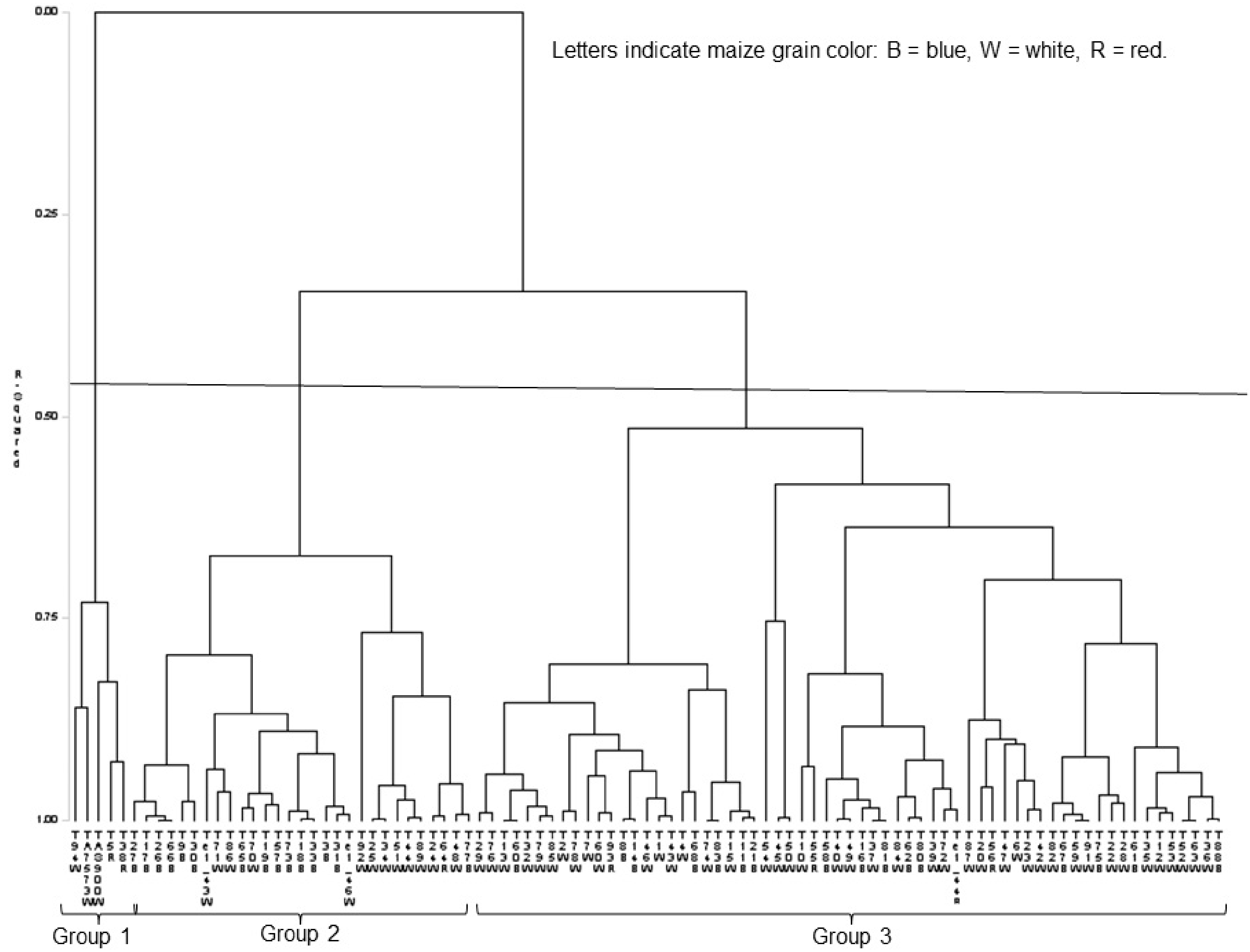

Fig. 3. Dendrogram obtained with Ward´s method, using six cornhusk morphological traits, measured in 97 maize populations from the Tehuacan region, of the Puebla state, Mexico.

Of the measured traits, cornhusk length and, to a lesser extent, ear coverage and peduncle weight were not influenced by environmental conditions within each region. In two regions, no interaction was observed between these traits and location. The remaining traits showed significant population × location interactions. The lack of significant population × location interactions for certain traits indicates that the relative differences in these traits among populations were not changed by the environmental conditions; however, the opposite occurred when the interaction was statistically significant ($P < 0.05$). In such cases, the populations changed their ranking order according to the analyzed trait across locations within regions (data not shown). This behavior is important for plant breeders because interactions between populations and environments alter the expression of cornhusk traits over time and with location, which may increase the utility of certain traits relative to others in breeding programs or indicate that certain populations may be more suitable in specific environments (Thillainathan and Fernandez, 2002) to observe improvements in genetic gain (Kang and Magari, 1996). It has been argued that characterization studies should include traits that are only slightly influenced by population × environment interactions (Sánchez et al., 1993). Thus, it can be concluded that the cornhusk length, ear coverage, and peduncle weight are the most desirable traits for cornhusk characterization and selection of genetic material for cornhusk production.

Group 1 in Fig. 3 and Table 5 included the improved hybrids evaluated in the Tehuacan region. The populations in this group had lower mean values for morphological traits compared with the populations included in Groups 2 and 3, which were composed of native populations with outstanding cornhusk traits. These results confirm the findings of Rice (2006) and King (2007), who stated that native populations had superior

Table 5. Mean values for morphological traits for the three groups defined in the dendrogram of the Tehuacan region. Puebla, Mexico.

Group	N†	Cornhusk length	Cornhusk width	Ear coverage	Cornhusk weight	Ear weight	Peduncle weight	Grain yield per plant
		cm			g			
1	5	18.28c‡	16.56c	8.20a	20.95c	71.18c	4.07c	65.52b
2	29	20.02b	21.22b	6.60b	34.59b	174.18b	7.59b	130.05a
3	63	21.03a	22.38a	6.04b	42.58a	220.80a	10.01a	149.94a

† N, number of populations.

‡ Means with the same letter in columns are statistically equal (Tukey, $P \leq 0.05$).

cornhusk quality and yield than the improved maize hybrids. Therefore, native materials should be considered in breeding programs designed to improve cornhusk production.

The composition of Groups 2 and 3 shown in the dendrogram in Fig. 2 include populations from the Teziutlan and Libres regions, which could be explained by the geographical proximity of these areas facilitating the exchange of genetic material. In traditional production systems, a constant exchange of seeds occurs (Latournerie et al., 2003; Gómez et al., 2004). Although this exchange is most common at the community level, it does not exclude flow from nearby or more distant communities (Keleman et al., 2009), which allows farmers to preserve their preferred materials and ensure their availability while also maintaining and creating diversity.

The group means and comparison of means test (Tables 4 and 5) showed that highest mean values of nearly all of the traits occurred in the Tehuacan region, which may have been a result of the systematic use of maize for cornhusk production in this region, which has led farmers to select for traits that are associated with a greater quantity and quality of cornhusk. In addition, farmers prefer white grain native populations that produce white cornhusks for both the national domestic market and international market. A close examination of the groups from the Tehuacan region (Table 5) revealed that Group 3 had the highest means for cornhusk-related traits. In addition, this group primarily consisted of white grain populations, suggesting that the genetic material of these populations had the greatest potential for cornhusk production.

Marmolejo (1995) reported that the production of cornhusk in the southern region of Nayarit, Mexico, was approximately 500 kg ha^{-1}. The estimates obtained in the present study were 258 kg ha^{-1} for the Tehuacan region, 169 kg ha^{-1} for Teziutlan, and 166 kg ha^{-1} for Libres. Obviously, different environments and genotypes were involved in each study. In addition, marketing cornhusks in Nayarit provides superior income; therefore, the farmers prefer high-yield cornhusk varieties (Rice, 2006); however, this preference is not observed in the regions of the present study. According to Marmolejo (1995), the cornhusks obtained in the Tehuacan region would fall within the PC-9 Quality category (23 cm long bracts) and are suitable for export. The cornhusks produced in the Libres and Teziutlan regions would fall into the PC-8 Quality grade, which is suitable for the international market, although shorter in length.

The traits that were measured in this study (particularly cornhusk weight, length and width, and ear coverage) were effective for grouping the populations by their place of origin and discriminating among populations. We suggest that these phenotypic attributes be used as selection criteria to identify promising maize populations for cornhusk production. Cornhusk weight is relevant because higher cornhusk yields increase the income that can be obtained from cornhusk commercialization. Thus, the sale of cornhusks in Puebla is an important strategic factor for improving the survival and income of family production units, which have the greatest economic restrictions (Viveros et al., 2010). Cornhusk length and width are related, and variations in these parameters are accepted in local, regional, national, and international markets; however, ear coverage is directly related to physical quality. Greater coverage indicates a lower probability of damage to the inner bracts by insects, birds, or from rotting caused by late season rain; thus, increased coverage results in a greater proportion of raw material (cornhusks gathered in fields) that is transformed into commercial product and a higher profit for those who sell cornhusks. Selection for the traits cornhusk length and ear coverage is already practiced in locations such as the Totonac region of Veracruz, Mexico, where the farmer selects ears with a sharp point created by long bracts and smaller ears that have a large amount of cornhusk (King, 2007). The use of these variables as selection criteria could also be valuable for selecting among native maize populations for improved cornhusk production in other maize growing areas.

In conclusion, the evidence from this study confirms that there is an abundance of genetic diversity for most of the evaluated cornhusk-related traits in native maize populations from the regions of Teziutlan, Libres, and Tehuacan in the state of Puebla, Mexico. The measured cornhusk traits in native maize populations were superior to those in the improved maize varieties. The region with the greatest potential for the production of cornhusks of high quality for national and international markets is Tehuacan, which had the highest values for all of the measured variables except for ear coverage. Thus, cornhusk weight, length and width, and ear coverage are proposed as phenotypic selection criteria for identifying potential maize populations and starting breeding programs for improved cornhusk production.

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