Maize diversity and ethnolinguistic diversity in Chiapas, Mexico

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The objective of this study is to investigate whether ethnolinguistic diversity influences crop diversity. Factors suggest a correlation between biological diversity of crops and cultural diversity. Although this correlation has been noted, little systematic research has focused on the role of culture in shaping crop diversity. This paper reports on research in the Maya highlands (altitude > 1,800 m) of central Chiapas in southern Mexico that examined the distribution of maize (*Zea mays*) types among communities of two groups, the Tzeltal and Tzotzil. The findings suggest that maize populations are distinct according to ethnolinguistic group. However, a study of isozymes indicates no clear separation of the region's maize into two distinct populations based on ethnolinguistic origin. A reciprocal garden experiment shows that there is adaptation of maize to its environment but that Tzeltal maize sometimes out-yields Tzotzil maize in Tzotzil environments. Because of the proximity of the two groups and selection for yield, we would expect that the superior maize would dominate both groups' maize populations, but we find that such domination is not the case. The role of ethnolinguistic identity in shaping social networks and information exchange is discussed in relation to landrace differentiation.

crop diversity | culture | Maya ethnic groups | cultural diversity

A correlation between biological diversity and cultural, or ethnolinguistic, diversity has been noted by ecologists (1), and crop scientists have likewise posited a relationship between crop diversity and cultural diversity (2). An association between crop diversity and cultural diversity is logical for several reasons. Anthropologists and geographers have noted that cultural groups often occupy distinct environments (3, 4) and that cultures are often defined by different production practices, food habits, and rituals that use crops (5). Moreover, the distinct knowledge systems and social networks that identify cultures are likely to influence the flow of seed among farmers, possibly creating culturally defined agricultural environments that are akin to other environments occupied and used by humans (6). However, most research on crop diversity (7) has focused on environmental adaptation and gene flow as the principal variables in explaining crop diversity, and the contribution that cultural diversity might make to generating and maintaining crop diversity has received little attention.

Maize Diversity in Mexico

Mesoamerica is a "megacenter" of biological diversity and one of the world's most culturally diverse regions, with >200 language groups. The region is also a center of domestication, crop evolution, and diversity both among and within crop species (8). Maize is Mesoamerica's premier crop, and maize diversity is greater in Mesoamerica than anywhere else. Edgar Anderson, a pioneer in the field study of Mesoamerican maize, observed long ago (9) that "maize is a sensitive mirror of the people who grow it," but no systematic relationship has been established between cultural diversity and biological diversity of maize in Mesoamerica. A cultural basis for biological diversity in maize is likely because of the central role played by conscious selection and exchange. Nevertheless, this cultural basis is obscured by natural selection (environmental adaptation), migration, and economic factors such as markets.

Comparison of case studies on Mexican maize agriculture reveals several common management features:

- Persistence of local maize types.
- Relative dominance of one or two types at both the household and community levels.
- Cultivation of minor varieties, which contribute minimally to overall production.
- High substitutability of different maize types for *tortillas*, the basic staple.
- Selection of seed from harvested ears, apparently based on an ideotype of local maize.
- Small but consistent acquisition of new seed from neighbors and more distant sources.

In sum, research on the maize systems of Mexico has shown them to be open but conservative in terms of seed management and farmer selection.

Race is the fundamental building block of conventional crop population biology of maize, as well as farmer management and crop improvement programs (10). The crop is conventionally divided into regional populations or races that are distinguishable by morphological, biochemical, and genetic markers (11). Continuous variation occurs among maize races in Mexico, although regional clusters or complexes are also apparent, each comprising several races that are more closely allied with one another and genetically more distant from races in other clusters. Ethnobiological research has shown that Mesoamerican farmers recognize and maintain several races within a single cropping system in response to microenvironmental and market factors (12, 13). Environment plays a well documented role in the regional distribution of maize types (14), but other possible factors have received only minor attention. In this article, we use the term "landrace" to refer to a population that is distinguished by farmers and oftentimes generically referred to as "*criollo*," meaning "local" maize. Farmers in Mexico recognize variation within landraces primarily by grain color, although other characters are sometimes taken into account. Here, we use the term "variety" to refer to variants of landraces that are named by farmers.

Consideration of the aforementioned research suggests four reasons for the likelihood that factors other than environment contribute to maize diversity. First, the ecogeographic analysis of maize races by Sanchez and Goodman (14) indicates that several races coexist as groups in a small number of genotype-by-environment (g $\times$ e) interaction zones. The higher elevations (>1,800 m) of the state of Chiapas constitute one broad g $\times$ e zone with Olotón and Comiteco as the two dominant races.

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Table 1. Characteristics of communities sampled for maize in the highlands of Chiapas in 2000

Ethnolinguistic group and municipality	Community	Common garden group*	Altitude, m above sea level	No. of households in community†	No. of households sampled for maize	No. of maize samples	Average maize planting, hectares
Tzotzil of Chamula	Los Ranchos	I	2,210	71	24	65	1.2
	Tentic	I	1,980	168	26	56	0.7
	El Crucero	II	2,470	87	26	52	1.5
	Pozuelos	II	2,380	79	36	80	0.8
	Totals				112	253	1.1
Tzeltal of Oxchuc	Pacbilna	III	1,860	117	32	78	1.1
	El Retiro	III	2,150	72	35	59	1.2
	Piedra Escrita	III	1,880	26	24	45	1.1
	Tushaquilja	IV	1,880	165	32	59	1.9
	Rancho del Cura	IV	1,980	137	33	72	1.9
	Totals				156	313	1.5

*Common garden groups used for analysis (see Table 4).
†No. of households in community from Instituto Nacional de Estadística Geografía e Informática (22).

Second, a small but regular exchange of seed material occurs beyond community boundaries (15). Third, farm-level research shows that Mexican farmers seek and test new maize types either as new varieties or as sources of new traits (16). Finally, there appears to be a high substitutability of maize types for the principal uses, such as tortillas and tamales (17). The interaction of g $\times$ e zones, seed flows, farmer selection, and substitutability should act to homogenize maize populations within similar environments, but, in fact, we find diversity of both principal and specialized (often colored) maize in relatively small regions, which is the case in highland Chiapas.

Study Site

Research was carried out between September 1999 and December 2002 in the highlands of Chiapas, Mexico, in municipalities surrounding San Cristobal de las Casas. Our study focused on maize populations and farmer knowledge in Tzotzil and Tzeltal communities in the municipalities of Chamula and Oxchuc at an altitude >1,800 m (Table 1 and Fig. 1). The Tzeltal and Tzotzil are widespread in Chiapas and extend into different altitude zones. Chamula and Oxchuc municipalities were chosen to minimize environmental differences between the farming areas of the ethnolinguistic groups under study. The climate of both municipalities is temperate, with rainfall concentrated in the summer and fall and averaging 1,000–1,200 mm per year. The region's eastern side, occupied by the Tzeltal, is slightly wetter. Neither the Tzotzils nor the Tzeltals have a centralized political unit; rather, they are loosely organized by community and municipality. Chamula has 107 predominately Tzotzil-speaking communities, and Oxchuc has 82 predominately Tzeltal-speaking communities.

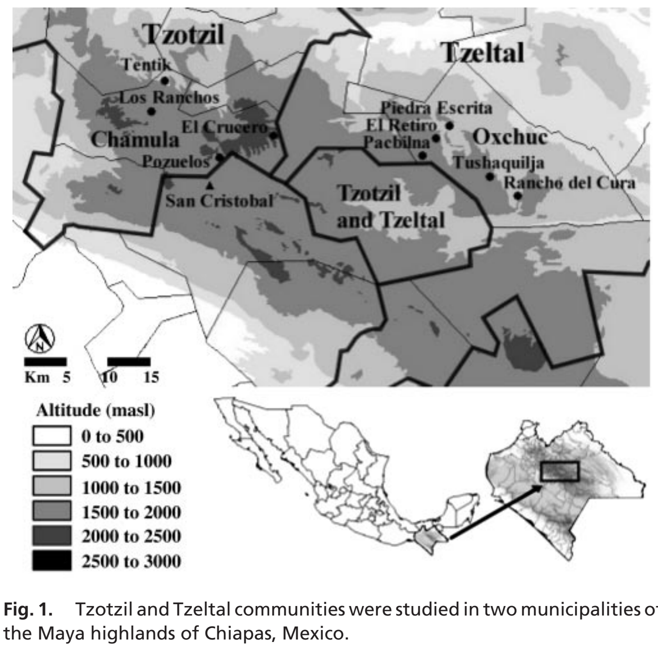

Fig. 1. Tzotzil and Tzeltal communities were studied in two municipalities of the Maya highlands of Chiapas, Mexico.

Chiapan maize constitutes a distinct regional cluster, with seven races characterized by late maturity, tall plants, 23–28 leaves per plant, many tassel branches, long ears, and extreme sensitivity to photoperiod and temperature (11). Above 1,800 m of altitude and in the lands of the highland Tzeltal and Tzotzil, the two most common races are Olotón and Comiteco (Fig. 2). In Mexico, Olotón is present only in Chiapas in the highlands. It is characterized by thick cobs, a bulky base with irregular rows, and large, rounded, flinty grains. Comiteco probably originated in Chiapas and is not found elsewhere in Mexico. It is characterized by very long ears (up to 35 cm), among other attributes. Bretting *et al.* (18) studied the maize of the nearby highlands of Guatemala and found that isoenzymatic variation between Olotón and Comiteco cultivated in Guatemala was not significant. Olotón maize from Mexico appears to be smaller than that found in Guatemala, whereas the reverse may be true for Comiteco.

Color is the single most important characteristic in Mayan farmer nomenclature, classification, and selection of maize (19, 20). Typically, different colors within a community are basically of the same race. Previous research in the midaltitudes (500–1,200 m) of Chiapas (17, 21) documented relatively widespread displacement of local varieties by improved ones, although landraces were maintained on marginal soils and by households with poor access to credit, fertilizer, and labor. In contrast, this study confirms that farmers in the highlands of Chiapas (i.e., >1,800 m in altitude) are similar to those in other highland regions in Mexico (13) in maintaining local maize and experiencing no major or lasting intrusion of modern varieties.

As shown in Table 2, the inhabitants of both municipalities practice small-scale, subsistence-oriented farming that is subsidized by off-farm employment and commerce. Land tenure combines communal ownership with individual use rights. Maize is the predominate crop throughout the region and is grown primarily as a subsistence crop. Our household surveys indicated that a small percentage of the households in Chamula and Oxchuc sold maize in 2000, whereas a minority of the households

Fig. 2. The two most common maize races of the Maya highlands are Olotón (*Left*) and Comiteco (*Right*).

in Chamula and half of those in Oxchuc reported being self-sufficient in the grain. A small but apparently regular amount of seed is acquired from off-farm sources in each municipality.

Materials and Methods

Four Tzotzil communities in Chamula and five Tzeltal communities in Oxchuc were sampled for maize. Households were randomly selected for sampling and data gathering. In the Chamula villages, we sampled 112 households, and in Oxchuc we sampled 156 households. A survey instrument was used to determine household characteristics, as well as maize names, characteristics, origin, and management.

Six ears of seed-quality maize were sought for each type sown by each farm household in the 1999 season. In all, 253 maize samples were collected in Chamula, and 313 were collected in Oxchuc. Maize samples (239 for Chamula and 260 for Oxchuc) were characterized for ear morphology (length, diameter, cob diameter, and seed length, width, and thickness), and 40 samples from Chamula and 49 samples from Oxchuc were measured for cob characteristics (rachis diameter, cupule width, and rachid length) by using a caliper and a microscope with an ocular micrometer. Group comparisons were based on averages for collections within communities.

Table 2. Household characteristics by community

Characteristic*	Tzotzil of Chamula	Tzeltal of Oxchuc
Tzotzil speaking, %	99.04	4.17
Tzeltal speaking, %	0.96	94.37
Spanish speaking, %	65.93	81.91
Income from commerce, %	20.13	6.46
Family members migrated for work, %	10.64	21.11
Planted maize in 1998, %	100	100
Sold maize last year, %	11.41	11.97
Maize harvest sufficient for household needs, %	35.85	50.17
Number maize types/household (mean, SD)	2.2 (0.2)	1.9 (0.2)
No. of years with seed lot (mean, SD)	30.6 (5.9)	27.2 (4.5)
Original seed lot from community, %	96.7	93.2
Origin of seed lot from parents, %	86.6	83.7
Yield of maize reported, kg/hectares (mean, SD)	936.6 (189.0)	589.7 (200.8)

*Percentages are for households unless otherwise noted. Source for language is ref. 22; otherwise, information is from field data.

Allele frequency was determined for eight isozyme loci for maize landraces pooled within four Tzotzil communities from Chamula and five Tzeltal communities from Oxchuc. Following Stuber *et al.* (23), Acp, Est, Idh1, Idh2, Me, Pgd1, Pgd2, and Phi were determined for 73 seeds from Chamula and 64 seeds from Oxchuc. Modern varieties Mo17, Tx303, and B73 were used as controls in each gel. Data were analyzed with Tools for Population Genetic Analysis (TFPGA) software. Among-population genetic structure was analyzed by hierarchical F statistics according to Weir (24). Nei's genetic distance (25) between communities was calculated, and an unweighted pair group method with arithmetic means dendogram was produced.

Reciprocal common gardens of maize landraces were planted in two communities in each municipality in 2001. The gardens' purpose was to provide data on local adaptation of the maize populations from the two municipalities. Thirteen maize varieties from the four communities of Chamula and 12 varieties from the five communities in Oxchuc were planted in a randomized complete block design with three replicates; landraces of the different colors were included for both municipalities. The plots were rented from local farmers and managed according to local practices but with more consistent fertilizer application (120:46 $N:P_2O_5$). The garden blocks comprised 5×5 m plots with three plants in 1×1 m hills, and data were taken from the central 3×3 m section of each garden block. Some experimental plots were lost, but in all cases at least two replicates per variety were included. Data were analyzed as a factorial experiment for each community (origin of seed $\times$ color) with SAS statistical analysis software general linear model procedures. Analysis of yield data showed no significant differences by color (for example, $F = 1.96$, $P = 0.1966$ for Los Ranchos and $F = 0.37$, $P = 0.8278$ for Piedra Escrita), so the garden data are presented by community and ethnic group irrespective of color.

Results

Survey information determined that 95% of the seed lots planted in the 1999 season originated in the community examined. A

Table 3. Phenological and morphological characteristics from reciprocal garden experiment for Tzotzil and Tzeltal gardens

	Tzotzil gardens			Tzeltal gardens		
	Seed origin			Seed origin		
Characteristic	Tzotzil	Tzeltal	*F*	Tzotzil	Tzeltal	*F*
n	71	61		76	71	
No. of days to tassel	123.14	139.53	21.10***	110.36	119.72	47.77***
No. of days to silk	136.21	149.10	13.62***	127.03	131.82	4.97*
Plant height, cm	292.54	312.46	7.82 ns	280.90	303.75	6.72*
Ear height, cm	149.00	163.36	6.09*	138.55	162.77	4.38*
Length of tassel, cm	48.13	47.72	0.67 ns	46.11	46.78	1.63 ns
No. of tassel branches	15.03	16.93	13.52***	15.50	16.41	2.12 ns
Length of ear, cm	16.13	18.16	22.08***	13.77	18.65	68.74***
Width of ear, cm	4.13	4.03	3.44 ns	3.94	4.12	4.42*
Length of grain, mm	10.56	10.62	0.02 ns	9.95	10.56	18.18***
Width of grain, mm	9.73	9.63	0.46 ns	9.66	9.96	5.57*
Thickness of grain, mm	5.91	6.04	2.78 ns	6.27	6.15	1.35 ns
Weight of grain, g	4.28	3.91	7.55**	4.16	4.51	9.36**
Cob width, cm	2.57	2.63	1.54 ns	2.42	2.62	15.74***

Significance level: *, 0.05; **, 0.01; ***, 0.001; ns, nonsignificant.

small (≈5%) but consistent proportion of introduced seeds lots was recorded in all communities. All five recognized colors were present in all communities. On average, Tzotzil and Tzeltal communities had 2.2 and 1.9 varieties per household, respectively. White and yellow maize types were equally common in the Tzotzil communities, but yellow types accounted for two-thirds of the maize area in Tzeltal communities. In Chamula, 20% of the households had red maize, in contrast to only 5% in Oxchuc, perhaps related to the fact that more than twice as many Tzotzil informants reported using red maize for medicinal purposes than did Tzeltal informants.

Maize collected in Tzotzil and Tzeltal communities suggests two distinct morphotypes that correspond to the Olotón and Comiteco races according to Wellhausen *et al.* (10). Statistical differences for morphological characters (e.g., row number, ear length, ear diameter, and grain thickness) distinguish the types from each community (data not reported).

Significant phenological, morphological, and yield differences were observed when landraces from both Tzotzil and Tzeltal communities were planted in reciprocal gardens (Tables 3 and 4). Varieties yielding poorly in one environment had much larger differences between tassel and ear onset than the same landraces in an environment to which they were better adapted. For example, Pozuelos (Tzoltzil) landraces planted in Rancho del Cura (Tzeltal) had a difference of 24.9 days, whereas in Pozuelos, the same landraces had only 10.7 days' difference (data not shown). When all landraces were analyzed by origin of the seed (Tzotzil vs. Tzeltal), we found that Tzotzil landraces were poorly adapted to the Tzeltal environments. In the Tzotzil environments, however, Tzeltal landraces showed contrasting results. When communities near the

Table 4. Yields (tons/hectare) of reciprocal gardens for 13 Tzotzil and 12 Tzeltal landraces

	Garden location			
	Tzotzil		Tzeltal	
Origin of seed*	Los Ranchos (I)	Pozuelos (II)	Piedra Escrita (III)	Rancho del Cura (IV)
By ethnic group				
Tzotzil	3.40 b	2.57 a	2.28 b	0.78 b
Tzeltal	4.05 a	2.01 b	3.95 a	1.52 a
n	35/33	37/33	38/37	38/34
	$F = 8.53$	$F = 6.97$	$F = 40.45$	$F = 23.42$
	$P_F = 0.0050$	$P_F = 0.0105$	$P_F = 0.0001$	$P_F = 0.0001$
By region				
Tzotzil				
Los Ranchos (I)	3.82 ab	2.19 ab	3.10 b	1.18 a
Pozuelos (II)	3.08 b	2.90 a	1.54 c	0.47 b
Tzeltal				
Piedra Escrita (III)	4.01 a	1.96 b	4.04 a	1.44 a
Rancho del Cura (IV)	4.17 a	2.15 ab	3.69 ab	1.75 a
n = (I/II/III/IV)	15/20/25/8	17/20/24/9	18/20/28/9	17/21/25/9
	$F = 5.41$	$F = 5.24$	$F = 24.64$	$F = 15.41$
	$P_F = 0.0025$	$P_F = 0.0030$	$P_F = 0.0001$	$P_F = 0.0001$

*Origin of seed by region includes communities closest to the common garden (see Table 1). ANOVAs for bifactorial experiment (origin of seed × color of variety); color of grain was nonsignificant in all cases (data not reported). Mean differences by Tukey's test (letters beside yields) are reported by common garden.

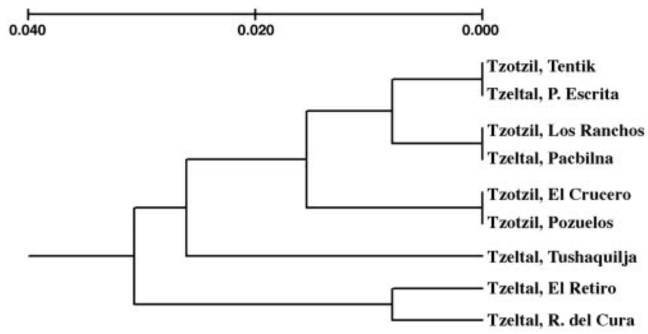

Fig. 3. Isozyme analysis shows weak differentiation and a lack of clustering of maize populations according to ethnolinguistic group.

common garden were defined as a single region, a similar pattern is observed: Tzeltal maize performed better in its own environments, but Tzotzil maize did not always show clear superiority in its environments. In the case of Los Ranchos (Tzotzil), local maize did not out-perform either Tzeltal maize or that of the other Tzotzil community (Pozuelos). In contrast, in Pozuelos, local maize had greater yield not only compared with the Tzeltal maize but also compared with the other Tzotzil landraces from Los Ranchos.

Thus, the common garden experiment suggests that there is a tendency for the maize populations from the region to be structured phenologically and morphologically and according to local adaptation, although adaptation is not clearly indicated across the entire study area. Only the Tzotzil maize showed clear adaptation to its own environments, performing poorly in Tzeltal environments. Tzeltal maize shows local adaptation but is also competitive in some Tzotzil environments.

Isozyme analysis indicates differences for allele frequencies in Tzotzil and Tzeltal varieties, although the analysis suggests very weak differentiation. A deficiency of heterozygotes was found for the whole sample ($F_{IT} = 0.4849$ and $F_{IS} = 0.4841$), suggesting some inbreeding (26). F_{ST} was very low (0.0019, not significantly different from 0), suggesting weak differentiation between ethnolinguistic subpopulations. These results are consistent with Pressoir and Berthaud's (27) findings for Bolita landraces from Oaxaca. Overall, Nei's genetic distance (25) was very small between Tzotzil and Tzeltal landraces (<0.02, i.e., 0.98 identity). Fig. 3 is an unweighted pair group method with arithmetic means dendogram based on the isozyme results, which shows that the maize populations of the two ethnolinguistic groups do not cluster according to whether the maize is from one or the other ethnolinguistic group (26).

Discussion

We found morphological and agronomic differences for maize landraces planted by Tzotzils of Chamula and Tzeltals of Oxchuc. Reciprocal garden experiments suggest local adaptation for Tzotzil landraces and wider adaptation for those of the Tzeltal. Isozyme analysis suggests a small genetic distance, and weak population differentiation shown by isozyme analysis suggests weak genetic differentiation. In conventional taxonomy of Mexican maize (10, 11), Tzotzil maize from Chamula is Olotón and Tzeltal maize from Oxchuc is Comiteco. Farmers in the two ethnolinguistically distinct municipalities maintain maize populations that can be identified according to traits that are easily recognized by them, especially grain color, flint vs. dent grain, ear length and weight, and the ratio of ear diameter to length. These populations are maintained despite seed movement between the communities, which might otherwise have pushed them to be less distinct. Indeed, the isozyme results suggest that variation does not correlate with ethnolinguistic differences, although morphological selection may have little effect on unlinked biochemical traits. These findings are compatible with those of Pressoir and Berthaud (27, 28) for maize landraces in the state of Oaxaca. The phenological and agronomic results from reciprocal gardens indicate that environmental adaptation may partially account for the maintenance of different populations, but a strong environmental basis for the differentiation between the two municipalities is lacking. It is arguable that the maize of Tzeltal farmers from Oxchuc is equally adapted to some areas in Chamula as the maize that is selected and maintained there by Tzotzil farmers. This finding suggests a possible role for ethnolinguistic diversity as a basis for maize diversity in this region and, more generally, in the unconscious selection and evolution of domesticated plants (29).

Although our research did not directly address the actual mechanisms involved in an association between maize diversity and ethnolinguistic diversity, two ethnographic observations are relevant. First, there is no strong differentiation between Tzotzil and Tzeltal people in terms of their use of maize. Our fieldwork found their cuisines and ritual uses of maize to be similar, and this similarity is confirmed by other ethnobiologists (19, 20). Second, farmers here, as elsewhere in Mexico, speak of "our maize," but they are interested and eager to try maize from outside their communities. For instance, when we offered to provide seed of any maize of our collections to farmers with whom we worked, 94% of the Tzotzil farmers requested maize from the Tzeltal communities, and 71% of the Tzeltal farmers requested maize from Tzotzil communities. Like other maize farmers who have been studied in Mexico, the Tzotzil and Tzeltal farmers of highland Chiapas use several criteria in their selection, but yield is always a major consideration. In this small-scale, subsistence farming economy, the struggle for self-sufficiency is often unsuccessful, and precious economic resources are spent on purchasing grain. As a consequence, the judgment of which landrace to plant is critically important. Because farmers change seed periodically or supplement existing stocks with new seed, it is essential that they trust the information about the maize they obtain from another source, and this confidence in the information source might be where ethnolinguistic differentiation contributes to maize diversity.

Human ecologists (30) define culture as a mechanism that organizes the flow of information essential for survival. Cultures develop traditional knowledge based on experience and adaptation to a local environment. Traditional knowledge is commonly well developed for genetic resources because of their paramount importance for the survival of communities practicing subsistence agriculture. The transmission of this knowledge is biased by language and local cultural differences; an example of this bias is individuals conforming to local practices because doing so is less costly than experimenting and learning (30, 31). Atran *et al.* (6) report that distinct folk ecological models affecting land use among the lowland Maya of Guatemala's Department of El Petén are significantly influenced by ethnic group affiliation and maintained by cultural segregation. Social networks of the different groups living in the region did not include people outside of an individual's ethnic group. This finding shows that socially acquired information is strongly bound to the ethnic group. We posit that the morphological separation between Tzotzil and Tzeltal maize arises when farmers seek to reduce the costs of obtaining essential information about a landrace's performance by seeking it locally from people who are trusted and in areas where it has been tested in familiar circumstances. Thus, the cost of information should bias farmers toward local landraces, thereby helping to segregate crop populations according to ethnolinguistic group.

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