Farmers' Genetic Perceptions Regarding Their Crop Populations: An Example with Maize in the Central Valleys of Oaxaca, Mexico[1]

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Soleri, Daniela *(Arid Lands Resource Sciences Program, University of Arizona, 1955 E 6th St, Tucson, AZ 85719, USA; Current address: Center for People, Food and Environment, 340 South Arboleda, Santa Barbara, CA 93110, USA and Institute for Social, Behavioral and Economic Research, University of California, Santa Barbara, CA 93106, USA, dsoleri@isber.ucsb.edu)* and **David A. Cleveland** *(Department of Anthropology and Environmental Studies Program, University of California, Santa Barbara, CA 93106-3210, USA, clevelan@lifesci.ucsb.edu).* Farmers' Genetic Perceptions Regarding Their Crop Populations: An Example with Maize in the Central Valleys of Oaxaca, Mexico. *Economic Botany 55(1): 106–128, 2001. Collaborative plant breeding is an approach to crop improvement that includes close attention to specific adaptation and interaction between farmers and formal plant breeders to better meet the needs of those farmers. Collegial interaction capable of making best use of the knowledge and skills of farmers and breeders will depend upon an understanding of those in terms that are relevant to each. To facilitate this interaction with the goal of making farmer selection practices more effective, the work described here sought to improve outside researchers' understanding of farmers' fundamental perceptions about their populations, growing environments, and expectations for response to selection. Various methods were used to accomplish this with a small sample of maize farmers in two communities in the Central Valleys of Oaxaca, Mexico. Farmers' decisions about maize varietal type repertoires imply assessments based on genetic and environmental variation in the local context. A clear distinction was made between traits of high and low heritability and expected response to selection, however, some traits of interest to farmers such as large seed size may involve considerations other than their potential for expression in the progeny generation.*

Opiniones Genéticas de los Granjeros con Respecto a sus Poblaciones de la Cosecha: un Ejemplo con Maíz en los Valles Centrales de Oaxaca, México. *El fitomejoramiento colaborativo es una forma de mejora de las plantas, que presta especial atención, a la adaptación específica y la interacción entre agricultores y fitomejoradores para un mejor respuesta a las necesidades de los primeros. Lo que facilita la interacción entre agricultores y fitomejoradores, pretendiendo que la selección de los agricultores sea mas eficiente. El trabajo describe una via para el mejor entendimiento de los investigadores en relación a las percepciones fundamentales de los agricultores respecto a sus poblaciones cultivadas, sus ambientes de cultivo y sus expectativas en relación con la respuesta a la selección. Varios métodos fueron aplicados a una pequeña muestra de agricultores en dos comunidades en los Valles Centrales de Oaxaca, Mexico. La decisión de los agricultores de escoger sus variedades esta basada en la variación genética y ambiental a nivel local. Una clara distinción fue hecha por los agricultores entre los caracteres de alta y baja heredabilidad así como la respuesta a la selección; pero, los resultados sugieren que algunos caracteres de interés para los agricultores como el tamaño del grano son importantes como criterio de selección, aun cuando no lo asocian con un efecto genético.*

Key Words: collaborative/participatory plant breeding; farmers' knowledge; genetic perceptions; maize; heritability; crop varietal classification; *Zea mays*; Mexico.

Collaborative plant breeding (CPB) is a relatively new approach to crop improvement (CGIAR 1997; Eyzaguirre and Iwanaga 1996; Witcombe et al. 1996). Though still under development, CPB involves some form of interaction between farmer-breeders and professional, formally trained plant breeders (hereafter, farmers and plant breeders, respectively) in crop improvement for local use (Cleveland, Soleri, and Smith

[1] Received 22 September 1999; accepted 5 September 2000.

Economic Botany 55(1) pp. 106–128. 2001

2000; Smale et al. 1998; Sperling and Loevinsohn 1996). In the context of CPB, a broad definition of plant breeding is emphasized that includes varietal choice, seed selection, and seed procurement (Cleveland, Soleri, and Smith 2000; CPRO-DLO and WAU 1999). CPB is seen as particularly relevant for agricultural systems in marginal growing environments, and there is frequently an emphasis on specific adaptation to local biophysical and sociocultural factors (Ceccarelli, Grando, and Booth 1996; Sperling and Scheidegger 1995; Weltzien et al. 1998). Marginal environments are characterized by multiple stress factors with high variance, resulting in low average and variable productivity (Falconer 1989). Crop varieties planted in these environments are frequently farmers' varieties (FVs), farmer managed and selected populations that include landraces, and locally adapted progeny from crosses between landraces and modern varieties. FVs are usually assumed to have relatively narrow geographical adaptation to marginal growing environments, and high yield stability (low variance across environments including years and locations) and moderate yield in those environments (Harlan 1992).

One form of CPB, and likely one of the most universally accessible, will be based on modest revisions of existing local selection methods to improve farmers' own crop populations, part of what has been referred to as ''farmer-led'' CPB (McGuire, Manicad, and Sperling 1999). Not only can this approach be economical, it has the potential to strengthen the extant selection process because a) it is based in the farming community and is less dependent on external experts and resources, b) the target environment (where populations will ultimately be grown and used) and selection environments are the same, thus eliminating any problem with lack of correlation between performance in selection plots and farmers' fields (Atlin and Frey 1989; Ceccarelli 1989), and c) it uses as its starting point crop populations that are locally adapted through a history of selection under local conditions (Ceccarelli, Grando, and Impiglia 1998).

The limited number of CPB efforts that include changes in farmers' selection practices typically involve a transfer of technology approach, especially regarding biological components (McGuire, Manicad, and Sperling 1999). For example, a project with maize farmers in Honduras attempted to teach basic genetics and techniques such as in-field plant selection, detasseling, and bagging to control cross pollination (Gomez et al. 1995).

However, it seems likely that understanding farmers' plant breeding in terms of the same theoretical principles that underlie professional plant breeding would enhance the probability for successful CPB both in terms of empowering local farmers socially, and of making significant biological progress in plant breeding. While an understanding of farmers' plant breeding in terms of professional plant breeding is of obvious importance for CPB, most research on farmers' plant breeding has focused on listings and classifications of farmers' varietal repertoires or on their stated selection criteria (e.g., Soleri and Cleveland 1993). One exception is Louette and Smale's work in Jalisco, Mexico (1998). They found that farmers' selection served primarily to maintain broad varietal phenotypes for ear characteristics, but that farmers did not undertake selection with the idea of changing their maize populations.

Not only will CPB likely require greater understanding of farmers' plant breeding, but methodological adjustments and innovations in professional plant breeding as well (CPRO-DLO and WAU 1999). Professional plant breeding has typically emphasized the development of modern varieties (MVs) with geographically wide adaptation to optimal (relatively low stress, and uniform) growing environments, and high yield in these environments (Evans 1993; Simmonds 1979). While there has also been attention to breeding for stress tolerance, this attention has focused on relatively large-scale environments and commercial farmers who can afford to purchase seed and other inputs, not on the farmers who are the topic of this paper (Bänziger, Edmeades, and Lafitte 1999; Heisey and Edmeades 1999). Thus, CPB will need to address the complexities of interdisciplinary (both within and between the social and biological sciences) and intercultural (farmers and researchers) collaboration, and of plant improvement in variable, stressful environments.

The research we report here is situated within the tradition of research on local (or indigenous) biological knowledge in terms of the nature of local knowledge, the conceptual level of this knowledge, and the purpose of understanding it. First, in terms of the basic views of local knowledge within ethnobiology we take an alternative approach, a middle ground, between utilitarian and intellectualist views (Berlin 1992, Medin and Atran 1999). The utilitarian view is a relativist one, that local knowledge depends on the goals, theories and beliefs of the local people. As Berlin notes, the utilitarian tradition is often dominated by economic concerns, or descriptions of uses, and this continues to be a strong tradition in economic botany and zoology. The intellectualist or comparativist tradition suggests that categories are recognized rather than constructed because nature itself is made up of an organized pattern of units, and there are universals in human cognition, resulting in cross-cultural similarities in the ways in which humans view or conceive biological organisms. A more inductive alternative to these two common approaches is one that unites them by seeking to explain both similarities and differences between local groups, including comparisons between local and scientific knowledge (Medin and Atran 1999).

Second, in terms of the level of knowledge, our focus is different than that of most studies of local knowledge of the biological environment, which have been on classification. This study contributes to a growing area of research on understanding more complex local biological knowledge systems, of which classification is an important part, and on the relationship between knowledge and practice. For example, Ellen (1999) concluded on the basis of his own and others' research on subsistence of rain forest peoples, that knowledge of general principles forms the basis for deductive models that function, for example, in connecting observations at the species level with forest structure and dynamics. Our focus is on local knowledge about complex functional relationships between organisms and their environments, namely the interactions between genotype and environment that determine phenotype in crop plants, and that affect varietal classification systems and farmers' plant breeding strategies.

Third, our goal of understanding similarities and differences between local and scientific knowledge is a practical one. Thus we are interested not only in the question of the extent to which local and scientific knowledge are similar or different, but also in how each can contribute to achieving farmers' and plant breeders' goals.

The research reported here is also based on two assumptions. First, the biological model of plant breeding described below is a valid representation of biological reality. Second, in CPB the knowledge and practice of both farmers and breeders are important, and neither should be assumed to be better a priori—their relative merits in terms of contribution to CPB need to be empirically assessed in each situation. This is the reason we have suggested collaborative plant breeding (CPB) as an alternative to participatory plant breeding (PPB) (Cleveland and Soleri 1997; Cleveland, Soleri, and Smith 2000).

This paper reports results of a small case study we carried out with farmers in two communities in the Central Valleys of Oaxaca, Mexico. We begin by very briefly describing the place of maize (*Zea mays* L.) FVs in Mexico and the study region, then use a basic biological model to outline relevant points regarding the interaction of genetic and environmental variation in crop populations, focusing on heritability. Our methods included traditional ones of social science, as well as a new method that uses hypothetical scenarios based on the biological model and farmers' own experiences to explore farmers' genetic perceptions—their knowledge of genetic variation and its relation to environmental variation—in terms of two components of farmers' plant breeding. First, farmers' perceptions of intervarietal differences through their descriptions of varieties of the most widely sown class of maize and our measurements of their maize populations, and the implications of those designations in terms of genetic and environmental variation. Second, farmers' perceptions of heritability for two different traits and correlation with plant development for one trait within their maize populations, through their criteria for seed selection, and responses to hypothetical scenarios.

For both of these components we asked three fundamental questions: (1) What methodologies can outside researchers use to understand farmers' plant breeding? (2) What is the nature of farmers' plant breeding knowledge in relation to the biological model of professional plant breeders? (3) Can this knowledge inform and improve CPB? The findings suggest both similarities and differences between the knowledge of farmers and plant breeders that have important implications for CPB.

Maize in Mexico

Mexico, the center of maize domestication and diversity, is also the home of the green revolution approach to developing MVs of wheat and maize for increased yield and production. In the Third World this approach is characterized by the application of industrial agriculture based on MVs and high levels of inputs in the better growing environments. In spite of the release of 222 MVs of maize (104 open-pollinated varieties, 118 hybrids) between 1966–1997 by the Mexican public sector, and 155 private-sector MVs (5 open-pollinated varieties, 150 hybrids) being available on the market by 1997, approximately 80% of the total maize area in 1996 (6.3 million ha) was in FVs (compared to 52% for all of Latin America) (Morris and López-Pereira 1999).

As with other major grain crops, high yielding maize MVs (as compared to FVs) have been bred for relatively optimal (fairly uniform, low stress) environments across wide geographic areas, and are relatively lacking in genetic diversity—limited work has been done on breeding for the more stress-prone environments of many small-scale farmers where yields are relatively low (Heisey and Edmeades 1999; Smith and Paliwal 1997). As discussed below, available data suggest that most maize MVs are not appropriate for small-scale farmers in Mexico, who are responsible for the majority of land planted to this crop (García Barrios and García Barrios 1994).

The low adoption rate for MVs is likely due in part to the highly stress-prone growing conditions (drought stress, low fertility, lack of inputs such as irrigation and fertilizers) of small-scale farmers in Mexico. Many MVs have not been targeted for such conditions, and thus produce lower yields than FVs (Aquino 1998; Heisey et al. 1998). Even if MVs performed acceptably in these farmers' fields, provided they supplied the additional inputs that the large-scale commercial farmers do (commercial fertilizers, pesticides, irrigation), low resource farmers cannot afford to supply these inputs. Yet small-scale Mexican farmers are often assumed to be ''only dimly aware of the potential benefits of improved germplasm and crop management practices,'' and lacking the education and skills needed to manage MVs ''properly'' (Aquino 1998:249), although no data are usually provided to support such statements. To the contrary, the few studies that have been carried out suggest that small-scale farmers make decisions in allocating resources to maize MVs v. FVs based on rational comparisons of performance, including yield stability (e.g., Perales, Brush, and Qualset 1998; Smale, Heisey, and Leathers 1995).

While it is difficult to compare yields for FVs and MVs at a regional or national level because most data are not disaggregated, some relevant survey data do exist. For example, disaggregated data from 1990 and 1994 surveys of 275 *ejidos* (communities managing land in common) show that in the spring-summer season with irrigation and fertilizer, MVs (''improved seeds'') yielded more (2.36 t/ha in 1990, 1.85 in 1994) than FVs (''local seeds'') with irrigation and fertilizer (1.36 t/ha in 1990, 1.37 in 1994), and yielded much more than local seed that were not fertilized or irrigated (0.84 t/ha in 1990 and 0.80 in 1994) (de Janvry, Gordillo, and Sadoulet 1997: 72). However, improved maize seed was used by only 4.6% (1990) and 15.5% (1994) of all farms, and only 3.0% and 7.8% of farms under 2 ha, which were almost entirely rain fed, and accounted for 28.8% of all farms (de Janvry, Gordillo, and Sadoulet 1997:78, 82, 32). These data support the observation that the adoption of maize MVs has generally been limited to better growing environments (Heisey and Edmeades 1999).

In the southern Mexican state of Oaxaca, 92.7% of maize area harvested in 1990 was in FVs, with the remainder in MVs (5.5% in open-pollinated varieties, 1.8% in hybrids) (Aragón Cuevas 1995). Grain yields in Oaxaca during this period were only 0.8 t/ha (INEGI 1996:32), 40% of the yield for Mexico as a whole, and 20% of the world average. In addition there are high rates of emigration from farm communities, and agriculture may often be associated with degradation of soil and vegetation (M. Rees pers. comm. 1998; Stephen 1991).

THE BIOLOGICAL MODEL: HERITABILITY

A central theme of biological scientific theory and practice, including plant breeding, is the relative contributions of nature (genetic variation, V_G) and nurture (nongenetic or environmental variation, V_E) to individual phenotypes. Variation in population phenotype (V_P), on which choice and selection are based, is determined by genetic variation (V_G), environmental variation (V_E), and variation in genotype-by-environment ($G \times E$) interaction ($V_{G \times E}$), ($V_P = V_G + V_E +$

$V_{G \times E}$). $V_{G \times E}$ represents the degree to which genotypes behave consistently across a number of environments. Environmental variation can be partitioned into several components: $V_E = V_L + V_T + V_M$ (V_L = variance due to location, e.g., soil and climatic variables; V_T = variance due to time, e.g., season or year; and V_M = variance due to breeder or farmer management). Low quantitative G $\times$ E means relatively little change in performance over environments. High quantitative G $\times$ E is characterized by marked changes in performance with changes in environmental factors and is associated with reduced stability of performance (defined as variance across environments) of an individual genotype. Qualitative G $\times$ E between two or more varieties means that they change rank across environments, and this is often referred to as a crossover because the regression lines for yield (or other traits) cross over at some point.

Broad sense heritability (H) is the proportion of V_P due to genetic variance (V_G/V_P), while narrow sense heritability (h^2) is the proportion of V_P due to additive genetic variance (V_A/V_P), that is, the proportion of V_G directly transmissible from parents to progeny, and therefore of primary interest in plant breeding. Heritabilities influence not only selection, but also choice of germ plasm for planting or crossing. Traits with high average heritability vary less with variation in the environment than traits with low average heritability, and therefore high heritability traits are theoretically easier to use in classification of crop genotypes.

Estimating the heritability of traits in particular environments and populations is of central interest to plant breeders (Nyquist 1991; Simmonds 1979). Traditionally, estimates have relied upon methods that attempt to characterize environmental variation through research design and the use of genetically defined materials, e.g., clones or families of full or half siblings. However, as increasing attention is being given to more marginal environments, interest in heritability estimates for these environments is growing (e.g., Bolaños and Edmeades 1996; Ceccarelli 1996). Consideration of heritability within the context of CPB requires attention to the potential for specific adaptation and farmer-breeder interaction. Attention to specific adaptation means heritability estimates made under the conditions experienced by farmers and their crop populations (Soleri and Smith n.d.). Attention to interaction suggests enhancing communication and understanding of researcher and farmer perspectives (e.g., Dhamotharan et al. 1997), for example by trying to understand the extent to which farmer plant breeding (knowledge, practice and genotypes, and environments) can be understood in terms of the basic biological model of plant breeding (Cleveland, Soleri, and Smith 2000).

Materials and Methods

This research was undertaken as part of a study of local maize populations and farmer selection in two communities in the Central Valleys of Oaxaca, Mexico (Soleri 1999). Communities in this area are predominantly either indigenous Zapotec, Mestizo, or a mix of these two (INEGI 1993:35). While off-farm work is increasingly important in this region, including temporary migration within Mexico and to the USA (M. Rees pers. comm. 1997; Stephen 1994), subsistence agriculture is still predominant and maize production is the foundation of most rural households' economy (INEGI 1993: 73). Eighty-eight percent of summer maize production in the Central Valleys is under rain-fed conditions with most households experiencing harvest failure about one of every four years (Dilley 1993:114). We worked with eight farm families in Santa Maria (pseudonyms are used for communities throughout), a community in the Zimatlan Valley, and with five families in San Antonio, a community in the Mitla Valley (Table 1). Households were initially selected for participation in another component of this research concerning quantitative description of their crop populations (Soleri and Smith n.d.). Some households were identified through recommendations of fellow community members and municipal authorities as households known to be managing diverse maize varieties or known as respected maize farmers (e.g., hardworking, not implying large-scale). Others were chosen during walking tours of fields in the 1996 spring planting season. The sample contained representatives of the main household types in each of the communities, based on the two most important distinguishing characteristics: gender of household head and wealth. Interviews were conducted with individuals primarily responsible for agriculture, typically a wife and husband, or mother and son, and younger workers who usually deferred to the primary pair. When we use

TABLE 1. CHARACTERISTICS OF STUDY COMMUNITIES IN THE CENTRAL VALLEYS OF OAXACA, MEXICO.

Characteristic	Santa Maria	San Antonio
Elevation (meters above sea level)[a]	1490	1780
Average annual precipitation (mm)[b]	685	468
Predominant soil characteristics[c]	alluvial, sandy clay	piedmont, gravel
District average maize yield (t/ha)[a]	0.76	0.45
Average sowing rate (seed/ha)[d]	47 000	40 000
Population (1995)[a,e]	2800	2533
Predominant ethnic/linguistic group[f]	Mestizo/Spanish	Zapotec/Zapotec

[a] INEGI 1996.
[b] Dilley 1993.
[c] Kirkby 1973.
[d] Based on field observations, Soleri 1996–1997.
[e] 1998 estimates for both communities = 3000, M. Rees personal communication 1998.
[f] INEGI 1993.

the word ''farmer'' in the rest of this paper, it refers to a farm household, unless otherwise indicated.

The larger study that this work was part of was conducted from June–December 1996, June–December 1997, and June–August and October 1998, with data collected in Spanish through participant observation, informal discussions, formal interviews, and on-farm and experimental plot research. Questions regarding farmers' varietal choices were administered during formal interviews in 1996 and 1997. Community-level comparisons between farmer estimates of maize cycle length (days from sowing to anthesis and harvest) were analyzed using the Mann-Whitney one-tailed test of medians with significance at $P \leq 0.05$.

In this research we investigated farmers' practices (varietal classification, seed selection) and farmers' genetic perceptions. Farmer identification of ear phenotypes they associate with white maize varieties was accomplished using a random sample of 100 ears from a plot in a farmer's field (measured as part of the larger study, Soleri 1999) in their community. Ten of each of the white maize varieties recognized in their community were identified by farmers. To compare the two farmer-identified varieties as represented by the 10 ear samples, we analyzed 15 morphophenological plant and post-harvest (seed and ear) traits using orthogonal contrasts with significance at $P \leq 0.05$ (Soleri, Smith, and Cleveland n.d.). All traits were measured on an individual plant basis and included traits measured post anthesis in the field: ear height, total plant height, stalk diameter, ear leaf width, ear leaf length, ear leaf area (width $\times$ length $\times$ 0.75, Lafitte and Edmeades 1994), number of primary tassel branches, anthesis silking interval (days between initiation of pollen shed and first silk emergence), days to anthesis from sowing; and traits measured post harvest: ear diameter, ear length, kernel row number, grain yield, weight of 100 grains, and shelling ratio (grain weight/ear weight).

Farmers' perceptions regarding heritabilities in their populations and environments were assessed during formal interviews in 1996, 1997 and 1998. We used hypothetical scenarios regarding traits that typically have high (tassel color) or low (ear length) average heritabilities, and their expression in both a variable, stressful, typical field of the region and in a hypothetical optimal field, one that is uniform and in no way limits plant growth (Table 2). Using the same two environmental types, we also asked about the effect of seed size on plant development. Here ''seed'' refers specifically to maize grain (also called kernels) used by farmers for planting. These scenarios built on farmers' experience, but also presented some situations unfamiliar to them, for example an optimal field without resources limiting plant growth. Our questions about the expression of traits in typical and optimal environments were designed to create a contrast in the variability present in the growing environment and the opportunity to discuss the interaction of this and V_G.

RESULTS

Our objectives were to test both a methodological approach for understanding how farmers perceive of abstract concepts such as heritability in their maize varieties, and to test hypotheses

TABLE 2. SUMMARY OF FARMER PERCEPTIONS OF HERITABILITY AND GENETIC VARIANCE FOR TWO TRAITS AND CORRELATION WITH PLANT DEVELOPMENT FOR ONE TRAIT IN MAIZE.

Phenotypic trait selected for	Question based on biological model	Scenario presented to farmers	Hypotheses regarding farmers' perceptions
Tassel color	How do farmers perceive the h^2 of a trait with high average h^2 in environments with high and low V_E?	What would be variation in tassel color if only seeds from plants with preferred tassel color planted?	Null: low h^2 Alternative: high h^2
Ear length	How do farmers perceive the h^2 and V_G of a trait with medium/low average h^2 in environments with high and low V_E?	What would be variation in ear length if only seeds from plants with long ears planted?	Null: low h^2 Alternative: high h^2
Seed size	How do farmers perceive the phenotypic correlation between traits with low heritability (seed size, plant development) in environments with high and low V_E? That is, would the phenotypic correlation between seed (endosperm) size and plant development ($V_{G\times E}$ where E = internal environment, i.e. endosperm) be overridden by field variability ($V_{G\times E}$ where E = field)?	What would be the variation in emergence, seedling size/vigor and grain yield when only large seeds planted?	Null: no phenotypic correlation between seed size and development of the plant Alternative: phenotypic correlation between seed size and development of the plant

about the similarities and differences between farmers' perceptions and those of plant breeders in terms of the biological model. These hypotheses were designed to provide insights into the nature of farmer knowledge underlying practices of particular relevance to CPB, for example, the possibility and nature of a theoretical basis for farmer knowledge and practices.

TABLE 3. MAIZE VARIETY CLASSIFICATION IN TWO COMMUNITIES IN THE CENTRAL VALLEYS OF OAXACA, MEXICO.

Name and color class	Varietal classification stated by farmers: Grain type	Varietal classification stated by farmers: Cycle length[a]	Community: Santa Maria	Community: San Antonio
blanco (white)	*cuadrado*	—	√	
	bolita	—	√	
	—	*tardón*		√
	—	*violento*		√
amarillo (yellow)	—	*tardón*		√
	—	*violento*	√	√
negrito (black)	—	*violento*	√	√
	—	—	√	
belatove (purple)	—	*violento*		√

[a] Determined by farmers' statements about both days from planting to anthesis and from planting to harvest.

V_G, V_E, AND VARIETAL CLASSIFICATION

Although Santa Maria and San Antonio are only approximately 65 km apart and both communities have good access to major markets, there is a distinct difference in farmers' naming practices regarding their white maize varieties in the two communities (Table 3). In both locations *blanco criollo* (local white) is the primary class of maize cultivated. In Santa Maria varieties of *blanco* are categorized solely based on features observed in the ear post harvest—particularly kernel/ear type (*cuadrado* v. *bolita*), as well as pigmentation of the cob and husk. In contrast, varieties of *blanco* in San Antonio are categorized on the basis of their cycle length (*tardón* [long cycle] v. *violento* [short cycle]), as measured by days to anthesis and harvest.

To obtain farmers' estimates of cycle length, we asked them to tell us the time from planting to flowering and to maturity for the *blanco* varieties they had experience with. Farmers responded in terms of months and fractions of months, sometimes adjusting this in terms of weeks or days (Table 4). Farmers in Santa Maria perceived *bolita* and *cuadrado* as having different cycle lengths, but they disagreed about

TABLE 4. FARMERS' ESTIMATES OF CYCLE LENGTH FOR *BLANCO CRIOLLO* MAIZE VARIETIES.

	Days from planting until:			
	Anthesis		Ready to harvest	
Santa Maria varieties	*Bolita* (n = 8)	*Cuadrado* (n = 7)	*Bolita*	*Cuadrado*
Mean	67	69	128	134
Standard deviation	10	8	15	22
Median	60	69	120	134
San Antonio varieties	*Violento* (n = 5)	*Tardón* (n = 5)	*Violento*	*Tardón*
Mean	68	81	105	144
Standard deviation	13	13	11	8
Median	60[a]	90[a]	105[a]	150[a]

[a] One-tailed Mann Whitney test of medians, significant at $P \leq 0.05$.

which was slower or faster, and the differences between cycle length estimates for the two varieties were insignificant. In addition, the lack of agreement regarding correlation between the *bolita* and *cuadrado* ear phenotypes and cycle length does not support the hypothesis that these ear types are indirect selection criteria for cycle length. In San Antonio, with a more stressful growing environment due to lower rainfall and poorer soils, the difference in farmer-declared cycle lengths was significant. Although farmers we spoke with in Santa Maria preferred the *bolita* phenotype, all stated that they grew mixed populations containing both varieties, and that keeping them separate was impossible because of cross-pollination.

Hibrido (hybrid) *blanco* is the only *blanco* maize currently distinguished by cycle length in Santa Maria. One household we worked with in that community grew it occasionally and purchased seed from suppliers in Oaxaca City, though a shop owner in Santa Maria also sold *hibrido* seed. *Hibrido* was universally known in both communities for its long cycle and greater water requirements as compared to local *blanco* varieties, and as a maize of foreign origin is not considered a *criollo* variety and was not included in this study. Color classes of maize other than *blanco* are grown in both communities—*amarillo, negrito,* and *belatove* in San Antonio, *amarillo* and *negrito* in Santa Maria. However, in both communities the non-*blanco* classes are typically assumed to be of short cycle length with the exception of long cycle *amarillo* populations reported in San Antonio and *negrito* of comparable cycle length as the *blanco* populations in Santa Maria (Table 3). None of the non-*blanco* color classes were described by farmers in either community as having consistent variants for ear or kernel type as was true of *blanco* in Santa Maria.

In addition to asking farmers what traits characterize their *blanco* maize varieties, we also asked farmers to identify ears belonging to different varieties from among the 100 ear samples we presented to them (Table 5). Of the 15 morphophenological traits measured on these ears and the plants that produced them, some within-community patterns are suggested by farmers' identification, though they were not always consistent and are not conclusive. Although only a few (n = 3) of the identification exercises with farmers from San Antonio used samples for which cycle length data were available, none of those comparisons showed significant differences between farmer identified *violento* and *tardón* groups of individual plants, as represented by their ears, for days to anthesis. Of all of the identification exercises conducted with farming households in that community (n = 8 households), six had at least one significant trait contrast between varietal groups. Of the total of 12 significant trait contrasts from that community, nine (75%) portrayed *violento* plants/ears/kernels as being smaller than those of *tardón.* The significant contrast for kernel row number showed *violento* with a higher row number. However, the most common significantly different trait (n = 3) from the exercises in that community was ear diameter, where results of two identification exercises showed a *violento* group with means greater than the *tardón,* while the other exercise had the opposite result.

Of a total of eleven identification exercises conducted in Santa Maria, seven contained varietal identifications with significantly different

TABLE 5. SIGNIFICANT ORTHOGONAL CONTRASTS[a] BETWEEN *BLANCO CRIOLLO* VARIETIES AS REPRESENTED BY FARMERS' CHOICES IN IDENTIFICATION EXERCISE FROM 100 EAR RANDOM SAMPLE[b].

	Trait means for farmer-identified varietal representatives, significant contrasts only										
Community & exercise no.	Total plant height (cm)	Flag leaf width (cm)	Flag leaf length (cm)	1° tassel branches (count)	Stalk diameter (mm)	Ear diameter (mm)	Ear length (cm)	Kernel row number (count)	Grain wt. (gm)	100 grain weight (gm)	Shelling ratio (grain wt/ear wt)
S Antonio[c]											
1										28.9/38.2	
2			86.3/97.5				12.9/15.4				
3						4.8/4.3		11.2/9.8			
4						4.8/4.4					
5			67.5/76.8								
6		8.1/9.2				4.2/5.0	12.4/13.8		77.7/125.0	32.5/44.9	
Sta Maria[c]											
1	266.9/243.4							9.2/11.4			
2	296.6/264.7										0.82/0.85
3		8.0/10.2		11.3/16.3		4.3/4.7	10.6/12.9		65.5/95.5		
4											0.85/0.88
5					1.7/2.0						
6									92.6/109.4		0.84/0.86
7			82.5/73.6								

[a] Significance at $P \leq 0.05$.
[b] Based on identification of 10 ears to represent each variety. Means of varieties identified by farmers in San Antonio: *violento/tardón*. Means of varieties identified by farmers in Santa Maria; *bolita/cuadrado*.
[c] Total number of identification exercises conducted in San Antonio: n = 8, in Santa Maria: n = 11.

means for one or more traits (n = 14 significant trait contrasts). Of these significant contrasts, 79% (n = 11) represented *bolita* as having smaller plant or ear characteristics as compared to *cuadrado.* In the comparison of farmer-identified varieties in this community, the most frequent (n = 3 households) significantly different trait was shelling ratio.

Heritability, Seed Size, and Intrapopulation Selection

The scenarios presented to farmers made use of traits with high and low average heritability that were familiar and of interest to them, as well as both familiar and unfamiliar growing environments (see Table 2 above). Our purpose was to create hypothetical situations to facilitate discussion of the abstract concept of heritability. Scenarios regarding seed size were intended to clarify farmers' perceptions of the significance of that trait in selection.

Tassel Color. Tassel, glume, and anther color (including yellow, red and purple), is an aesthetic trait that farmers in both communities pointed out to us. The pleasure of looking across a field of green plants with purple tassels was the reason one household in San Antonio sought out a yellow maize population known to have tassels of that color. In Santa Maria a household was growing a *bolita blanco* population recently developed by a family member to have predominantly purple tassels, cobs, and husks; purple husks transfer their color to tamales steamed in them, a desired effect. Tassel color is highly heritable and as such is among the pigmentation traits used to identify genotypes in experimental research (Coe, Neuffer, and Hoisington 1988: 135).

These scenarios were designed to improve understanding of how farmers perceive the influence of V_G and V_E on expression of tassel color. The potential role of V_G was represented by the relationship between phenotypes of maternal and progeny generations. The potential role of V_E was represented by the contrasting growing environments. The null hypothesis was that farmers see a relatively small contribution by V_G to total V_P—low heritability—saying that seeds from plants with a given tassel color would produce plants with a diversity of tassel colors when planted in a typical environment, and mostly tassels of the given color when planted in an optimal environment, attributing V_P predominantly to V_E and $V_{G \times E}$. The alternative hypothesis was that farmers see tassel color primarily determined by V_G, that the tassel color of the progeny plant would be the same as that of the parent regardless of the environment. Our hypotheses did not include the effects of the pollen parent or of segregation in the formation of progeny phenotypes, although some farmers did mention this.

Using photographs from a local population of maize that included plants with both purple and yellow tassels, we asked farmers what tassel color would result if seed were only taken from plants with purple tassels and those seed were planted in 1) a typical field, and, 2) an optimal field (Fig. 1). The majority of responses to these scenarios stated that tassel color would be purple in either field; that is, it will not be affected by the growing environment (Table 6). The remainder stated that there would be a mixture of colors, and that after five years of isolation from cross pollination with other populations and continued selection for that color, the population would have all purple tassels.

Ear Length. Ear length is one of farmers' central selection criteria in both communities (Soleri, Smith, and Cleveland n.d.), and is a trait with medium to low average heritability (<0.50) (Hallauer and Miranda 1988). Again, our scenarios were designed to elicit farmers' perceptions about the relative influence of genetic and environmental sources of variation on V_P of this trait. The null hypothesis was that farmers see a relatively small contribution by V_G to total V_P, saying seeds from long ears would produce plants with a diversity of ear lengths when planted in a typical field and mostly long ears when planted in an optimal field. The alternative hypothesis was that farmers see ear length primarily determined by V_G, with progeny phenotype for the most part the same as that of the parent, regardless of the environment. As with tassel color, our hypotheses did not include the effects of the pollen parent or of segregation in progeny phenotypes although these were noted by some farmers.

We asked what would be the length of the ears produced in a typical field as compared to those produced in a optimal field, if they planted only seed from the long ears from a typical harvest of variable sized ears (Fig. 2). The farmers stated that the typical field would produce a harvest of variable ear lengths while the harvest from

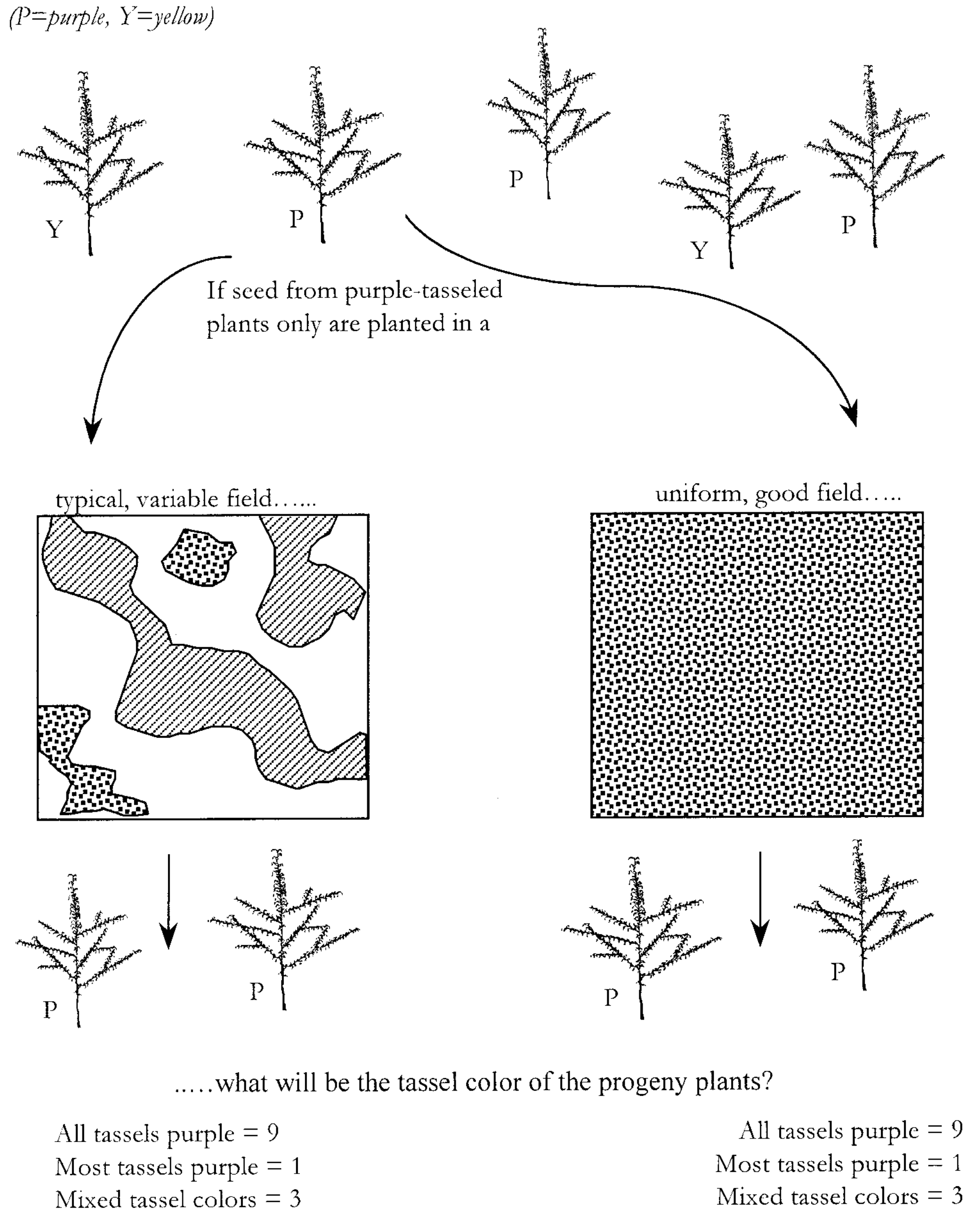


Fig. 1. Genetic perceptions: Responses to tassel color scenario. (P = purple, Y = yellow).

the optimal field would consist of uniformly long ears, and gave environmental reasons when asked why this would occur (Table 7). One farmer noted that there would always be some variation present in any environment.

Seed Size. Some studies have found a significant relationship between seed size and early plant growth (e.g., Revilla et al. 1999). Participant observation, discussions and formal interviews during our first field season (1996) clearly indicated that, as with ear length, farmers found large seed size desirable but completely dependent on the environment in which the plant grew. To avoid questions that would seem redundant to the farmers, we did not present scenarios regarding heritability for seed size as we did for tassel color and ear length. Instead, we wanted to ascertain why large seed size was

TABLE 6. FARMERS' RESPONSES TO GENETIC PERCEPTIONS SCENARIOS REGARDING HERITABILITY AND GENETIC VARIANCE OF TASSEL COLOR.

Scenario/question		No. of households	Response	Total	Sta. Maria	S. Antonio
What will be the tassel color of plants grown from seed selected only from seed parents with one tassel color (either purple or yellow), when grown in a(n):	Typical field?	13	All same color as seed parent	9	5	4
			Most, but not all of seed parent's color	1	0	1
			A mixture of colors	3	3	0
	Optimal field?	13	All same color as seed parent	9	5	4
			Most, but not all of seed parent's color	1	0	1
			A mixture of colors	3	3	0
Will there be more of that color if isolated and selected for 5 years? (if did not answer "all same color as seed parent" above)		4	Yes	4	3	1
			No	0	0	0

sought out for planting. Therefore, in subsequent interviews we focused on discerning farmers' perceptions of differences between large and small seeds that might explain their preferences for large seed.

Our question was, Do farmers perceive a correlation between seed phenotype (size) and other phenotypic traits of the plant that grows from that seed, such as seedling vigor? The null hypothesis was that farmers would see no correlation, saying that later developmental stages would be the same for big seeds and small seeds when planted in an optimal field, and similarly, they would be the same in a typical field. The alternative hypothesis was that later developmental stages would not be the same for big seeds and small seeds, that a correlation exists. Effects of seed size on subsequent stages within one generation can be a genetic effect due to pleiotropy, linkage, or epistatic effects, or may be entirely due to seed size per se.

Two comparably large ears, one with small seeds and the other with large seeds, but otherwise similar, were used to demonstrate these scenarios. We asked farmers to imagine that in both a typical field, and an optimal field one row of each seed type is planted with identical spacing, one seed per hill, and only ears produced by single ear plants considered. We also asked farmers more specifically what major problems they have in the first month after planting, and referred to those answers in explaining our question about the effects of seed size in a typical field. We asked if there would be any differences in a typical field between large and small seeds. The majority of farmers (10) answered that there would be no differences, with a minority (3) stating that larger seeds emerge better and produce larger seedlings in the typical field they are familiar with (Table 8).

Since more farmers initially provided more detailed answers about differences in an optimal field, we asked farmers more specifically if there would be differences in emergence/seedling size and vigor, plant size, or grain harvested when large and small seeds were planted in an optimal field. The majority of responses suggest that these farmers see seed size as having no consequence for plant performance, implying no phenotypic or genetic correlation between these traits. A total of three households stated that there would be differences in some aspect of seedling/plant performance associated with dif-

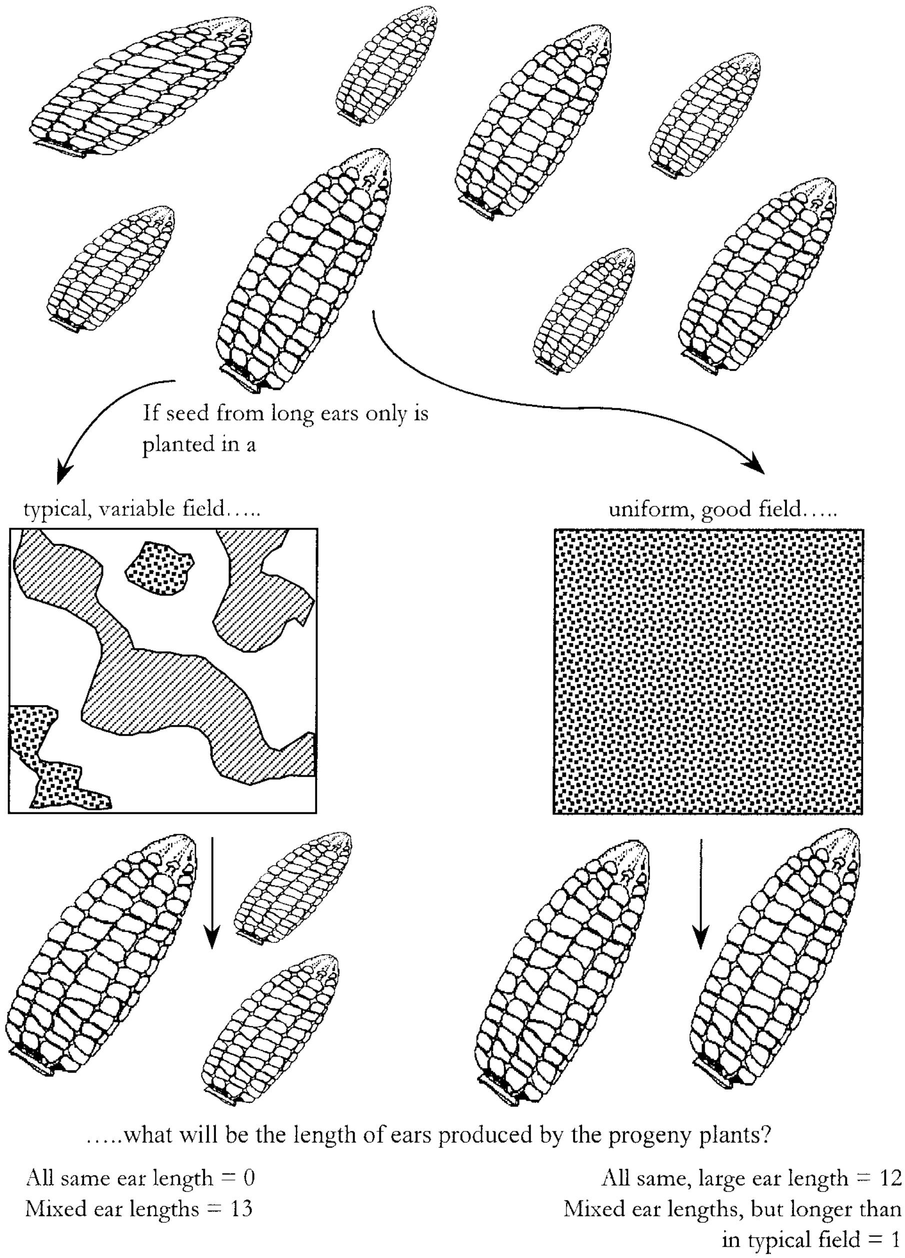


Fig. 2. Genetic perceptions: responses to ear length scenarios.

ferent seed sizes: in emergence (two), seedling size/vigor (two), and yield (one).

Altogether, four households said that there would be differences between large and small seeds in either a typical or optimal field. Responses that differences in seed size will result in differences in seedling/plant performance in both types of fields (two households) can be interpreted as suggesting a genotypic correlation between these that is evident regardless of environmental variation. The response of one household that there was a difference only in an optimal but not in a typical field suggests a genetic correlation may exist but is masked by the

TABLE 7. FARMERS' RESPONSES TO GENETIC PERCEPTIONS SCENARIOS REGARDING HERITABILITY AND GENETIC VARIANCE OF EAR LENGTH.

Scenario/question		No. of households	Response	Total	Sta. Maria	S. Antonio
If only seed from long ears are selected, what size will the ears be that are produced when those seeds are sown in a	Typical field?	13	All long	0	0	0
			All short	0	0	0
			Mixed sizes	13	8	5
	Why?	10	Environment determines everything	8	4	4
			Water determines	1	1	0
			Nothing limiting growth	0	0	0
			Soil determines	1	1	0
If only seed from long ears are selected, what size will the ears be that are produced when those seeds are sown in an	Optimal field?	13	All long	12	7	5
			All short	0	0	0
			Mixed sizes	1	1	0
	Why?	10	Environment determines everything	7	3	4
			Water determines	0	0	0
			Nothing limiting growth	1	1	0
			Soil determines	1	1	0
			There is always some variation	1	1	0

variation present in a typical field, and therefore not reflected in phenotypic correlation between seed size and seedling/plant performance where there is high V_E and $V_{G\times E}$. The response of one other household that there is a difference only in typical fields suggests that the advantages of large seeds are only evident under stress. However, due both to the small sample size and the complex nature of the relationships involved, the findings are only suggestive and further research is required. One farmer provided the following explanation: This is why we (farmers here) do not use small seeds, this is what we think will happen (poorer seedling vigor), but we do not know this for certain because we never plant small seeds because that is not our custom here. To be sure of what the results would be we would need to try it for a while.

Finally, since the majority of farmers said that there were either no differences in performance between large and small seeds, or that any differences in early plant development did not result in differences at harvest, we asked them why they select/purchase large seeds for planting, mentioning that they cost more, and provide fewer seeds per unit volume (maize is sold by volume). Most households (nine) offered no reason except custom for selecting large seeds. However, three households (the three who said that larger seeds produced larger and/or more vigorous seedlings in an optimal field) reiterated that a reason for planting larger seeds is because they produce larger seedlings. Finally, the one household responding that there would be a difference in a typical field, stated a possible reduction in seed size over generations if large seed were not selected, implying recognition of the possibility of a genetic component to seed size and that selecting large seed size maintains this characteristic in a population, rather than changing the population.

DISCUSSION AND CONCLUSIONS

The results of this study address the three fundamental questions we posed at the beginning of this paper. First, the genetic perceptions scenarios proved to be a useful method for outsiders to communicate with farmers about, and to understand the abstract conceptual bases of, farmers' plant breeding. Second, the results provide theoretical and empirical insights into farmer plant breeding knowledge and practice in terms of the biological model of plant breeding. Third,

TABLE 8. FARMERS' RESPONSES TO GENETIC PERCEPTIONS SCENARIOS REGARDING THE EFFECT OF SEED SIZE.

Question	Households	Answer	Total	Sta. Maria	S. Antonio
What are major problems in first month after planting maize seed (more than one response possible)?	13	Lack of water	12	7	5
		Insect larvae	6	5	1
		Ants	5	3	2
		Birds	3	2	1
		Weeds	2	2	0
		Rats, lizards	2	0	2
		Disease	1	1	0
With large v. small seeds sown in a typical field, are there any differences?	13	Yes (larger seed emerges better, gives larger seedling)	3	3	0
		No	10	5	5
With large v. small seeds sown in an optimal field, are there differences in[a]:					
All differences	13	Yes	3	3	0
		No	10	5	5
Emergence?	13	Yes	2	2	0
		No	11	6	5
Seedling size/vigor?	13	Yes	2	2	0
		No	11	6	5
Amount of grain harvested?	7	Yes	1	1	0
		No	6	3	3
Why select/purchase large seed for planting?					
Answers of households that never said large seeds different than small ones	9	Who knows?	1	1	0
		Our custom	2	1	1
		No difference, same type of seed	6	2	4
Answers of households that said large seeds different than small ones in a typical or an optimal field or both	4	If we don't, seeds will become smaller over the years	1	1	0
		Larger seeds produce larger seedlings	3	3	0

[a] Some households responded positively to more than one consequence of differences in seed size.

these insights appear to have potential for informing and improving CPB.

In the remainder of this section we discuss the results regarding farmers' varietal classification and intrapopulation selection, and the usefulness of the insights this information provides for CPB.

V_G, V_E, and Varietal Classification

The objectives, methods and results for the investigation of varietal classification within *blanco criollo* are presented in Table 9. Farmers indicated that they recognize a concept parallel to V_G by their use of distinctly named varieties. In the case of Santa Maria, both varieties as conceived by farmers may be present within one population. We hypothesize that the contrast in *blanco criollo* varieties between Santa Maria and San Antonio reflects, in part, differences between their growing environments. In Santa Maria, aside from *hibrido,* no distinct *blanco* varieties were identified as being maintained for allocation to particular environments determined by variation between locations, years or other factors among fields cultivated by that community. San Antonio farmers, on the other hand, say that they maintain *blanco* varieties based on their different performances in response to V_E, specifically year-to-year variation in timing and amount of precipitation. Attention to cycle length in San Antonio may be one reason that despite gene flow through seed exchange and subsequent pollen movement there is a significant difference in days to anthesis between white maize populations evaluated from these two communities (Soleri 1999).

These findings suggest that intrafield V_E appears greater to farmers in Santa Maria than V_E between fields/years and, therefore, maintaining separate varieties (distinct sets of V_G) for different fields/years is not worth their effort. This is not the case in the eyes of San Antonio farmers. Rather, the findings suggest the hypothesis that one of the factors contributing to farmers' maintenance of distinct varieties of a class of maize (*blanco* in this case), is those farmers' assessment of the magnitude of V_E among their growing environments and the costs and benefits to them of maintaining each variety. Evidence from two communities in the Sierra Juarez de Oaxaca supports this hypothesis as well (Soleri et al. 1998). Those communities are both located at 2500 m above sea level, their maize fields are distributed across a 300 m range of elevations and farmers maintain distinct local white maize varieties specifically for two or even three different classes of field elevations. Whether or not this classification and use of varieties according to specific environments is based on genetic differences, and if it occurs simultaneously with the post-harvest oriented distinctions reported in Santa Maria (*cuadrado* v. *bolita*), cannot be determined from this study but would have implications for population V_G.

The result that farmer categorization of varieties by duration in the ear identification exercise in San Antonio was not supported by phenological measurements of plants from which selected ears came complicates interpretation of farmers' comments and practices, makes drawing conclusions difficult. The simplest conclusion regarding the San Antonio identifications is that these cycle length categories are the result of poor observation by the farmers. However, the consistent interest in cycle length in San Antonio, the efforts made to seek out planting material based on this, and other evidence of farmers' astute observations do not support this argument. The findings suggest a number of other explanations of what may be occurring. It could be that the ears in the identification exercise simply did not present adequate or familiar variation for distinctions to be made. It may also be that when they enter the community, *violento* varieties may be identified by ear or kernel phenotypes as is done in the market place. However, after years of cultivation (and cross-pollination) in local fields, those ear and kernel phenotypes are no longer so obvious and distinct. Instead, the sorting by cycle length may be occurring in farmers' fields intentionally sown to a particular variety that experiences conditions eliminating or reducing the presence of individuals of a different cycle type. This is particularly plausible if we assume that alleles contributing to ear and kernel phenotypes and cycle length are segregating independently of one another. This hypothesis is also supported by field data showing a significant difference in days to anthesis between a farmer-identified *violento* population and others identified as *tardón* (Soleri 1999). Finally, a different standard for kernel phenotypes of newly acquired seed of different cycle varieties as compared to seed saved on farm for these same varieties may also help explain the results of this study.

TABLE 9. SUMMARY OF OBJECTIVES, METHODS AND RESULTS[a] FOR THE INVESTIGATION OF VARIETAL CLASSIFICATION OF *BLANCO CRIOLLO* MAIZE VARIETIES.

Question	Method	Results: Sta. Maria	Results: S. Antonio
		Farmers' stated assessments	
What are farmers' declared varieties of local *blanco* maize?	Formal interviews	Two varieties based on ear and kernel morphology. *Cuadrado* and *bolita.*	Two varieties based on cycle length. *Violento* and *tardón.*
What are farmers' estimations of cycle length of their local *blanco* maize varieties?	Formal interviews	Cycle length estimates for *cuadrado* and *bolita* are not significantly different.	Cycle length estimates for *violento* and *tardón* are significantly different.
		Farmer classifications analyzed in field trials	
Are the ears (and the plants they came from) identified by farmers in post harvest selection as representing different *blanco* varieties actually different?	Ear identification exercise. Farmer identification of *blanco* varieties based on ear and kernel morphology. 10% identification from 100 ear samples. Plant and ear traits measured on farm and post harvest.	85% of significant contrasts showed *cuadrado* as having larger ear or plant characteristics compared to *bolita.*	No identifications showed significant differences between *violento* and *tardón* for cycle length.
Is there a significant difference in reproductive phenology between farmer-declared long and short cycle *blanco* varieties in S. Antonio?	Comparison with orthogonal contrast of days to anthesis of varieties in farmers' fields.	Not appropriate.	The *violento* populations (n = 2) had significantly shorter days to anthesis than did the *tardón* populations (n = 2).

[a] Significance at $P \leq 0.05$.

TABLE 10. SUMMARY OF FARMER PERCEPTIONS OF HERITABILITY FOR TWO TRAITS AND CORRELATION WITH PLANT DEVELOPMENT FOR ONE TRAIT IN MAIZE.

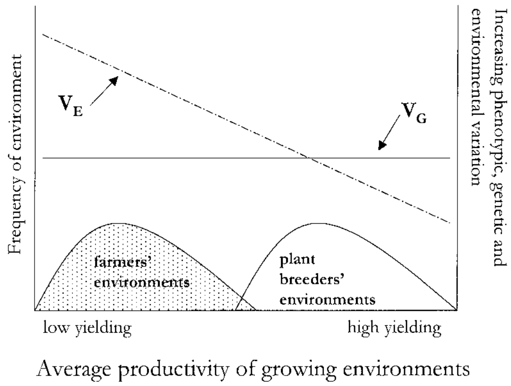
Phenotypic trait selected for	Observed; expected	Farmers' responses: Observed and expected frequencies based on null hypotheses about phenotype variation (tassel color, ear length) or correlation (seed size) in field that is — Typical: None	Typical: Some/much	Optimal: None	Optimal: Some/much	Conclusions
Tassel color	Observed	9[a]	4[a]	9	4	Most farmers perceive V_G of traits with high h^2 even in environments with high V_E. A minority sees some variability due to segregation.
	Expected (null hypothesis: low heritability)	0	13	13	0	
Ear length	Observed	0	13	12	1	Most farmers do not perceive V_G of traits with low h^2; V_G is swamped by V_E. A minority does see V_G.
	Expected (null hypothesis: low heritability)	0	13	13	0	
Seed size	Observed	10	3	10	3	Most farmers do not explicitly perceive any phenotypic correlation between seed size and plant development. A minority does perceive this, and it is a reason for selecting large seeds for planting.
	Expected (null hypothesis: no positive phenotypic correlation between seed size and development of the plant)	13	0	13	0	

[a] Chi square significant at $P \leq 0.05$.

HERITABILITY, SEED SIZE, AND INTRAPOPULATION SELECTION

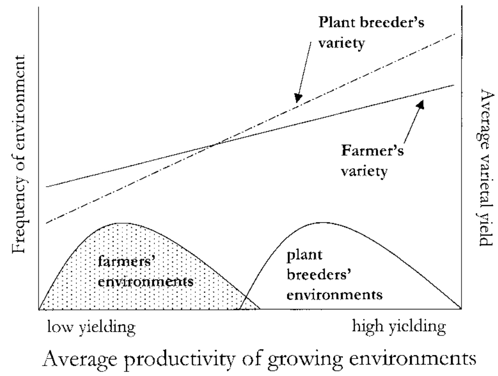
The hypotheses, results, and conclusions for the investigation of intrapopulation variation are presented in Table 10. Farmers' responses to the genetic perceptions scenarios showed general agreement among farmers regarding high and low heritability traits. Genetic variation and the capacity to select from it were clearly recognized for the high heritability trait, tassel color. Here, farmers see phenotypic variation consistently expressed despite contrasting environments, and they attribute this variation to a nonenvironmental source. In contrast, based on the design of our scenarios, farmer responses indicated that for traits with medium to low average heritability most farmers perceived no V_G, e.g., an optimum environment will produce uniform phenotypes. These responses can be interpreted in two other ways. First, perhaps there is no V_G for these traits in these populations. This seems unlikely based on seed procurement practices in the region (Smale, Aguirre, and Bellon 1998), potential for cross pollination, and Oaxaca's location in the region of origin and diversification of maize (Doebley 1990). Second, farmers' categorization of all phenotypes being the same, ''*van a estar todos iguales, parecidos*'' (they will all be the same, identical) may actually include a certain level of variation that an outsider might categorize as being different. We tried to address this possibility by pointedly questioning respondents in this regard, ''*¿Es decir, exactamente parecidos en todos sus aspectos*?'' (That is to say, exactly the same in all ways?). Given the findings of this small study neither of these explanations appear likely and it seems best to limit our interpretation to the original one outlined above, that farmers perceive of no V_G for low h^2 traits.

In the Central Valleys of Oaxaca, where variation among years and soils and moisture availability even within fields is substantial (Dilley 1993; Kirkby 1973), farmers' responses are overwhelmingly that ''the environment is everything'' for some traits of interest to them such as ear length. They clearly distinguished between two traits of low average heritability (ear length, seed size) and a trait with high average heritability (tassel color), and their expectations for response to directional selection reflect this. Still, this research was only a beginning step in understanding the complexities of these farmers' selection. For example, it is difficult to ascertain



** Same population (V_G) compared across range of environments. Assumes low yielding environments are characterized by high variability relative to high yielding ones as in Oaxaca study.*

Fig. 3. Graphic representation of the hypothesis of experience limiting perceptions and theory: farmers' experience of V_E obscuring contribution of V_G to V_P*.



**Partially based on Ceccarelli 1989.*

Fig. 4. Graphic representation of hypothesis of experience limiting perceptions and theory: range of V_E experienced by plant breeders limiting their anticipation of G × E*.

farmers' motivation for seeking large seed size even in the face of greater costs to themselves as was the case in the 1997 summer planting season, when the price of maize seed for planting was approximately 30% greater than that of maize grain of the same variety for eating at the two markets nearest Santa Maria and San Antonio. Most households (9, see Table 6) did not give a reason for selecting/purchasing large seeds or said that it was a custom, despite widespread recognition that it has no consequences in terms of changing population traits. It is not clear whether this preference for large seeds is based largely on unarticulated recognition of their physiological superiority, or is based on custom or aesthetics. Our planned experiments on the effect of seed size on seed viability and seedling vigor for farmers' varieties should help to illuminate the biological situation. However, while determining the original motivation for a contemporary practice would be difficult, this should not preclude the possibility that a concern for seed viability and seedling vigor was a factor in its origin.

Three farmers said that they select large seed because of the larger seedlings they produce, but only one of them implied a potential for heritability of seed size. Therefore, it seems appropriate to consider the following hypothesis: although farmers consider seed size to be a trait related to seed and seedling performance, most consider seed size the result of the maternal plant's growing environment and not inherited, making their low expectations for genetic response irrelevant in determining how and why they conduct their selection (Louette and Smale 1998 had similar findings). Still, care must be taken to avoid rationalizing farmer practices beyond what can be convincingly tested simply to satisfy researchers' desires for a mechanistic logic underlying those practices (Richards 1995).

These findings indicate that the limits of farmers' theory must be understood in context. As with formally trained researchers, it appears that most farmers base their understanding of V_G and h^2 on their own experiences. As such, farmers' responses may not so much deny the presence of V_G in their maize populations for traits of low average h^2, but reflect their unfamiliarity with optimal growing environments and indicate the overwhelming influence of V_E in local fields, obscuring V_G in low h^2 traits (Fig. 3). Similarly, it has been suggested that the theory underlying some plant breeders' practices reflects their experiences (Ceccarelli 1989, 1996; Cleveland n.d.). For example, contrasting assumptions among plant breeders regarding appropriate selection environments for highly stress-prone target environments have been attributed to contrasting experiences with range and type of V_E, affecting the likelihood of anticipating the genotype × environment interactions that might occur in the marginal fields of many farmers (Fig. 4).

When challenged with these imaginary situations, some of the components of which they are familiar with, some farmers made sophisticated analyses of the determinants of V_P suggesting an understanding similar to that of plant breeders. For example, two of the households we worked with pointed out that even after five cycles of isolation and selection for a highly heritable trait such as tassel color, occasional nonselected phenotypes will still occur—a few yellow tassels among the population selected for purple tassels—a result that outside researchers would attribute to crossing and segregation in a heterogeneous population.

Overall, the variation in farmers' responses is not surprising, given the variability in the distribution of expertise and inquisitiveness that is a frequent finding of researchers, for example in regard to genetic resources (Friis-Hansen 1996) or propagule selection (Boster 1996; for a general review see Berlin 1992: Chapter 5).

Implications for Collaborative Plant Breeding

These genetic perceptions discussions with farmers were not undertaken as tests of their knowledge, nor was their knowledge being compared against a correct or scientific template. We recognize that many other factors that lie beyond the realm of this work contribute to farmers' knowledge and practices regarding their crops, including sociocultural, economic, and individual variables (Berlin 1992).

A genetic perceptions-style approach attempts to neutralize the realm of practice—in this case selection and crop improvement—to the extent that the dichotomy between scientific and nonscientific practice is abandoned and the common elements contributing to farmer and breeder practice, such as theory, are recognized. The greatest obstacle to this has typically been the hierarchy of knowledge implicit in many conventional approaches to agricultural research and extension, particularly in the context of low resource, small-scale agriculture (Chambers 1993). Though we are well aware that our approach is still clearly grounded in the western scientific paradigm, the hope is that attempting to be cognizant of the limits of that paradigm serves to ameliorate the bias of that grounding.

This research provides early empirical evidence that farmers' knowledge and practice concerning varietal choices, including seed procurement patterns, and selection strategies and practices are at least partially based on theory—fundamental perceptions about their crop populations and growing environments and the interaction between them. Thus, while documentation of the specific patterns and practices themselves is valuable, it seems likely that identifying and understanding the perceptions that underlie them may ultimately provide more versatile tools for the development of CPB.

It may be that a more profound understanding of farmers' genetic perceptions could contribute to more appropriate educational efforts that go beyond a hierarchical transfer of technologies such as experimental design, stratified selection or pollination control, and provide farmers with conceptual tools they can use to adapt or develop their own innovations to best meet their needs (Bentley 1989; Cleveland and Soleri 1991). Finally, giving plant breeders and other researchers an appreciation for the reality of the challenges facing farmers, the theory contributing to how farmers address those challenges, and the situation of theory among other factors in the formation of both farmers' and researchers' practices may facilitate real collaboration and the benefits it has to offer.

Acknowledgments

We thank the farming households in Oaxaca who taught us much and brought great patience and good humor to our work together, and the municipal authorities of the study communities for permission to conduct this work. Thanks to Estudios Rurales y Asesoría (ERA) and Union de Comunidades Forestales Zapoteco–Chinantecas (UZACHI) of Oaxaca for sharing information and discussions regarding the Sierra Juarez communities. We also thank M. Smale and M. E. Smith for valuable discussions and advice relating to this work; Humberto Rios Labrada for translation of the Spanish abstract; three anonymous reviewers for Economic Botany, one of who provided particularly valuable suggestions for improvement. Special thanks to S. E. Smith for stimulating discussions and assistance in many forms with this work. This study was supported in part by grants to DS from the American Association for University Women, Association for Women in Science; Research Training Grant for the Study of Biological Diversity, University of Arizona; Sigma Xi; the US–Mexico Fulbright Commission; and the USAID–CGIAR Linkage Program; grants to DAC from the Committee on Research, Faculty Senate, UC Santa Barbara; and financial and logistic support of the Economics Program of CIMMYT through M. Smale, and the Maize Program of CIMMYT through S. Taba.

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