Environ. Biosafety Res. 4 (2005) 141–166
© ISBR, EDP Sciences, 2006
DOI: 10.1051/ebr:2005019

Understanding the potential impact of transgenic crops in traditional agriculture: maize farmers' perspectives in Cuba, Guatemala and Mexico

Daniela SOLERI[1*], David A. CLEVELAND[1], Flavio ARAGÓN C.[2], Mario R. FUENTES L.[3], Humberto RÍOS L.[4] and Stuart H. SWEENEY[5]

[1] Environmental Studies Program and Geography Department, University of California, Santa Barbara, 2302 Girvetz Hall, Santa Barbara, CA 93106, USA
[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Campo Experimental Valles Centrales, Melchor Ocampo No. 7, Santo Domingo Barrio Bajo, Etla, Oaxaca, México
[3] Instituto de Ciencia y Tecnología Agrícolas (ICTA), ICTA 231, 01064 Villa Nueva, Guatemala
[4] Instituto Nacional de Ciencias Agrícolas (INCA), San José de Las Lajas, La Habana, Cuba, CP 32700, GP#1
[5] Geography Department, University of California, Santa Barbara, 3611 Ellison Hall, Santa Barbara, CA 93106, USA

Genetically engineered transgenic crop varieties (TGVs) have spread rapidly in the last 10 years, increasingly to traditionally-based agricultural systems (TBAS) of the Third World both as seed and food. Proponents claim they are key to reducing hunger and negative environmental impacts of agriculture. Opponents claim they will have the opposite effect. The risk management process (RMP) is the primary way in which TGVs are regulated in the US (and many other industrial countries), and proponents claim that the findings of that process in the US and its regulatory consequences should be extended to TBAS. However, TBAS differ in important ways from industrial agriculture, so TGVs could have different effects in TBAS, and farmers there may evaluate risks and benefits differently. To evaluate some potential impacts of TGVs in TBAS we used the RMP as a framework for the case of *Bt* maize in Mesoamerica and Cuba. We interviewed 334 farmers in Cuba, Guatemala and Mexico about farming practices, evaluations of potential harm *via* hypothetical scenarios, and ranking of maize types. Results suggest high potential for transgene flow *via* seed, grain and pollen; differences in effects of this exposure in TBAS compared with industrial agriculture; farmers see some potential consequences as harmful. Perceptions of harm differ among farmers in ways determined by their farming systems, and are different from those commonly assumed in industrial systems. An RMP including participation of farmers and characteristics of TBAS critical for their functioning is necessary to ensure that investments in agricultural technologies will improve, not compromise these agricultural systems.

Keywords: transgenic / maize / genetic engineering / risk management / farmers / traditional agriculture / seed system / gene flow / third world / Mexico / Cuba / Guatemala / Mesoamerica / Caribbean

Abbreviations: FVs: farmers' locally selected crop varieties; **MVs:** plant breeders' modern crop varieties; **RMP:** risk management process; **TBAS:** traditionally-based agricultural systems; **TGVs:** genetically engineered, transgenic crop varieties; **TGFVs:** genetically engineered, transgenic, FVs; **TGMVs:** genetically engineered, transgenic, MVs.

INTRODUCTION

Genetically engineered transgenic crop varieties (TGVs) are a central focus of agricultural development efforts today (CGIAR, 2005; FAO, 2004; Hilbeck and Andow, 2004; Monsanto Company, 2004), and probably the crop technology with the most potential to affect Third World agriculture since the Green Revolution varieties were introduced 40 years ago (James, 2004).

The potential effects of TGVs in traditionally-based agricultural systems (TBAS) of the Third World are very controversial. The issues are in many ways the same as

* Corresponding author: soleri@es.ucsb.edu

Table 1a. Study country maize systems including comparison with US.

Location	2004 maize production (MT × 10^3)[1]	2002 maize consumption, (MT × 10^3)[1]	2003 maize imports, (MT × 10^3)[1]	2003 maize imports from US (MT × 10^3)[2,3]	Use of farmer saved seed (%)[4]	Fertilized area as percent of maize area[5]	TGV crop area sown (million ha)[5]
Cuba	300.0	3.9	329.7	329.6	NA	NA	NA
Guatemala	1072.3	1094.4	532.0	494.1	91	53	0
México	20 000.0	12 708.3	5764.1	5589.6	79	43	0.1
USA	299 917.1	3870.8	337.3	–	0.01	100	47.6

[1] FAO Statistical Service (FAOSTAT Data, 2005).
[2] US Department of Agriculture, Foreign Agricultural Service (USDA FAS, 2005).
[3] These have all increased in 2004 (MT × 10^3): Cuba 484.1, Guatemala 542.8, Mexico 5613.5 (USDA FAS, 2005).
[4] (Aquino et al., 2001).
[5] (James, 2004).
NA = not available.

those in industrial systems — benefits and risks to humans and the environment, consequences of unintentional gene flow, intellectual property rights, and the socioeconomic structure of agriculture. However, the issues are also different in important ways, because TBAS differ from industrial agricultural systems (Tab. 1a).

Characteristics of TBAS

A characteristic of TBAS important for their effective functioning is integration within the household or community of crop production, food consumption, plant breeding, seed multiplication, and genetic resource conservation. This contrasts with industrial agriculture where these functions are institutionalized, specialized and separated. TBAS also contrast with industrial agriculture in terms of growing environments, crop genotypes and sociocultural variables.

Growing environments

TBAS farms often consist of a number of small, scattered fields with marginal growing environments — relatively high levels of stress and temporal and spatial variability, with few external inputs. Yields are often lower (Tab. 1b), but yield stability often greater with FVs than would be the case if MVs were being grown. This is because MVs often have steep regression response curves, *i.e.* are highly responsive to marginal environments, as well as optimal ones (Ceccarelli, 1997; Evans, 1993: 308ff; Simmonds and Smartt, 1999: 347ff).

Crop genotypes

Farmer varieties (FVs) dominate TBAS and consist primarily of landraces selected by farmers, but also progeny from crosses between landraces and modern varieties (MVs), and MVs adapted to farmers' environments by farmer and natural selection (sometimes referred to as "creolized" or "degenerated" MVs) (Zeven, 1998). A higher level of genetic diversity in FVs, including intraspecific genetic diversity (Frankel et al., 1995) frequently supported by extensive gene flow (Louette et al., 1997; Pressoir and Berthaud, 2004), is presumed to support horizontal resistance to multiple biotic and abiotic stresses (Brown, 1999). Many centers of crop origin and diversity are dominated by TBAS. Farmers often continue to use FVs, even when MVs are available, because their adaptation to marginal growing environments reduces production risks, and because MVs may be agronomically, culinarily, and economically inappropriate (Ceccarelli et al., 1994; Evans, 1993; Heisey and Edmeades, 1999). FVs are valuable not only for farmers, but for the *in situ* conservation of genetic diversity for the formal breeding system.

Society and culture

TBAS farmers typically use low levels of external inputs, have limited access to government programs and markets, and limited influence on policies affecting them, resulting in high production risks and risk aversion (Ellis, 1993; Hardaker et al., 1997). Farmers' production knowledge combines understanding based on theory and empirical

Table 1b. Study site descriptions including comparison with national and US data. T = more traditional community, M = more modern community.

Location	Annual average precipitation (mm)	Elevation (masl)	2003 population ($\times 10^3$)[1]	2003 per capita gross national income (USD)[2]	% population in agriculture, 2003[1]	Average maize yields 2004 (MT/ha)[1]
Cuba	–	–	**11 300**	**NA**	**15.2**	**2.7**
La Palma, Pinar del Río (T)	1660[3]	50–80[3]	35.43[4]	144[5]	5.0[6]	0.8[7]
Mayorquín, Holguin (M)	1017[8]	44[9]	72.8[10]	168[10]	49.0[10]	1.5[10]
Guatemala	–	–	**12 347**	**1910**	**48.1**	**1.8**
El Rejón, Sacatepequez (T)	1700	1400–1650	27.8	NA	NA	1.6[11]
La Máquina, Suchitepequez (M)	1350	48	49.9	NA	NA	2.4[11]
México	–	–	**103 457**	**6230**	**21.7**	**2.5**
Santa Inez Yatzeche, Oaxaca (T)	746.6	1460	1.2[12]	529[12]	63.0[12]	0.9[13]
Comitancillo, Oaxaca (M)	909.2	70	3.6[12]	2248[12]	27.5[12]	1.4[13]
USA	–	-	**294 043**	**37 870**	**2.0**	**10.05**

[1] FAO Statistical Service (FAOSTAT Data, 2005) for national data.
[2] World Development Indicators, World Bank (http://www.worldbank.org/data/dataquery.html) for national data.
[3] Estación meteorologica La Palma. Pinar del Río, Cuba, 2004 (average precipitation for last 11 years).
[4] Oficina Municipal de Estadística. La Palma, Pinar del Río, Cuba, 2003.
[5] Dirección municipal de economía y planificación. La Palma, Pinar del Río, Cuba, 2004 (annual salary paid to workers by government).
[6] Sector Cooperativo y Campesino. La Palma, Pinar del Río, Cuba, 2004.
[7] Empresa de Cultivos Varios, La Palma, Pinar del Río, Cuba, 2004.
[8] Estación Territorial de Investigaciones Agropecuarias de Holguín, Grupo de Granos, 2003 (average precipitation for last 18 years).
[9] Catastro Municipal, Velasco, 2003.
[10] Oficina municipal de estadística, Gibara, Holguin. 2003. Gross national income data is average annual salary paid to workers by government.
[11] (Instituto Nacional de Economia, 2004).
[12] (INEGI, 2005) Approximation calculated from employment and salary data for 2000.
[13] (SAGARPA, 2004).
NA = not available.

observation with values about the social and cultural significance of farming, often focused on FVs (Hernández Xolocotzi, 1985; Soleri et al., 2002). Food production relies on household labor (Ellis, 1993), with most households selling a portion of their production in the market, though they are incompletely integrated into these markets. Off-farm income is often critical for households' overall survival strategy, and may reduce the importance of on-farm production, for example, migration of household members may lead to labor shortage (Narayanan and Gulati, 2002). It may also lead to reduced time and other resources devoted to seed selection or conservation of crop genetic diversity, and eventually loss of knowledge on which they depend.

The importance of TBAS for future food production

Even though yields in TBAS are low, food production there is essential for feeding a significant proportion of the world population now, and will likely be necessary in the future, even with production increases in large-scale, industrial agriculture (Heisey and Edmeades, 1999). It has been estimated that by 2025 three billion people will depend on agricultural production in TBAS (Falkenmark, 1994) (cited in Evans, 1998; Goklany, 2002). Not only are resources not available to replace the food production in TBAS, neither are they available to transform TBAS into modern industrial agriculture (Narayanan and Gulati, 2002).

The risk management process

The risk management process (RMP) is the standard institutional approach to risk in the industrial world, not only for TGVs, but for new technologies generally, including novel biological entities such as invasive species (NRC, 1996; NRC, 2002: 54-55). There are four key steps in the RMP, although they may be organized and labeled in different ways: (1) *identification* of a hazard (or potential risk), (2) *analysis* of the probability of (a) *exposure* to a hazard and (b) *harm* resulting from exposure (Risk = P(E) × P(H)), (3) *evaluation* (or perception, assessment) of harm, and (4) *treatment* (or management, regulation) of risk by reducing exposure and harm.

Many proponents of TGVs for TBAS view the RMP in the industrial world as adequate for TBAS, based on the assumption that conditions are not significantly different. Many opponents view TGVs and the RMP as inherently unsuited for TBAS. Both of these positions are based on untested assumptions and are scientifically unsound (Cleveland and Soleri, 2005). Current scientific opinion supports a middle ground — the RMP for TGVs in TBAS must be based on the specific characteristics of TBAS, because "…the specific genomic, organismal, population genetic, ecological, and socioeconomic context influences the affect of biological novelty" (NRC, 2002: 36) (see also FAO, 2004: 4; Snow et al., 2005). This position is increasingly taken in agricultural policy, *e.g.* "Transgenic research must be done with adequate safeguards under scientifically based protocols approved by each developing country" (Millennium Project, 2005). The problem is that the necessary research to support a rigorous RMP of TGVs for TBAS is just beginning (Hilbeck and Andow, 2004), and compared with the funding for the development of TGVs and for their promotion in TBAS, support for this research is minimal.

TGMVs and TBAS

All commercial TGVs are modern varieties (TGMVs), although some transgenic FVs (TGFVs) are being developed (*e.g.*, Fitt, 2004). Despite disagreements about TGMVs and appropriate risk management in TBAS, both proponents and opponents generally recognize the: (a) dramatic spread of TGMVs globally, from 1.7 to 81.0 million hectares between 1996 and 2004, being 5% of the total crop area (James, 2004), including in the Third World, where over 27.6 million hectares in 11 countries were sown to TGMVs in 2004, 34% of the global area in TGMVs; (b) importation into TBAS countries of large amounts of grain containing TGMV seed (especially from the US) (USDA FAS, 2005), (c) high probability of unintentional transgene flow, including into centers of diversity, *e.g.*, maize transgenes documented in Mexican FVs by some studies (Alvarez-Buylla, 2003; Alvarez-Morales, 2002; Quist and Chapela, 2001), the effects of which may often be irreversible (Ellstrand, 2003a), though their presence or persistence is disputed by one study (Ortiz-García et al., 2005); (d) rapid development of third-generation TGMVs, including maize, that produce pharmaceutical and industrial chemicals (Andow et al., 2004; Ellstrand, 2003b); and (e) need for participation of those potentially affected is essential, not only in evaluating risks, but in all four steps in the RMP (Frewer, 2003; NRC, 2002), as well as in broader benefit-cost analysis (Nelson et al., 2004).

The risk management process as an analytical framework

Based on the previous points, we assume that TGMVs can be a hazard in TBAS, and that it is critical to understand the potential for TGMVs to harm current functioning of TBAS. We use the RMP as a framework, realizing that providing cost estimates of potential harm from TGMVs is a necessary step for a broader analysis of the potential of TGVs for TBAS (NRC, 2002), including potential benefits of TGMVs (Goklany, 2002), as well as benefits and costs of existing MVs and alternatives including transgenic FVs (TGFVs) and the products of participatory plant breeding (Murphy et al., 2005). One trial run of comparative benefit-cost for *Bt* maize in Kenya on a limited, exploratory scale, identified the need for much more data (Nelson et al., 2004).

Our research used a simple interview methodology to rapidly and inexpensively document farmer practices, knowledge and values relevant to aspects of transgene risk management for maize in Cuba, Guatemala and Mexico. The focus was on two aspects of the RMP addressed most readily by this approach: potential for exposure and evaluation of harm. Data were collected on (1) farmer practices and farm characteristics affecting potential for unintended exposure to transgenes, (2) farmers' evaluation of (a) relative importance of yield potential *vs.* yield stability,

Table 2a. Characteristics of farmers included in study (average and standard deviation unless otherwise noted). T = more traditional community, M = more modern community.

Location (*n*)	Age	Years formal education	# in household	Indig. households% (number)	Have relatives abroad % (number)	Have heard of TGV maize (%) (number)
Cuba (114)	**51.97 (14.49)**	**8.54 (3.82)**	**3.58 (1.36)**	**0.00**	**48.25 (55)**	**6.14 (7)**
La Palma, Pinar del Río (T) (56)	53.93 (14.21)	8.07 (4.08)	3.66 (1.50)	0.00	51.79 (29)	5.36 (3)
Mayorquín, Holguin (M) (58)	50.05 (14.63)	8.89 (3.52)	3.50 (1.22)	0.00	44.83 (26)	6.90 (4)
Guatemala (110)	**48.60* (16.87)**	**2.48 (2.54)**	**5.99 (2.52)**	**52.88 (55)***	**28.18 (31)***	**10.91 (12)***
El Rejón, Sacatepequez (T) (55)	41.74 (15.01)	2.65 (1.99)	6.40 (2.49)	98.18 (54)	7.27 (4)	1.82 (1)
La Máquina, Suchitepequez (M) (55)	55.33 (15.97)	2.31 (3.00)	5.60 (2.50)	2.04 (1)	49.09 (27)	20.00 (11)
México (110)	**56.95* (12.15)**	**3.84* (3.95)**	**5.02* (2.33)**	**100.00 (110)**	**50.91 (56)***	**11.82 (13)***
Santa Inez Yatzeche, Oaxaca (T) (55)	54.62 (12.57)	2.84 (3.62)	5.51 (2.35)	100.00 (55)	90.91 (50)	3.64 (2)
Comitancillo, Oaxaca (M) (55)	59.27 (11.36)	4.84 (4.03)	4.53 (2.22)	100.00 (55)	10.91 (6)	20.00 (11)
Total	**52.51 (14.97)**	**4.97 (4.35)**	**4.84 (2.33)**	**50.30 (165)**	**42.51 (142)**	**9.58 (32)**

* Significant difference between communities in same country, t-test for continuous variables. χ^2 test of independence or Fisher's exact test for categorical variables, $P < 0.05$.

(b) direct potential harm from hypothetical *Bt* transgenes in maize, and, (c) relative harm expressed in preferences for sowing and eating different types of maize varieties.

This study was motivated by the need for an RMP for transgenic maize in Mesoamerican and Caribbean TBAS, into which transgenic maize is rapidly spreading amidst heated controversy, and which include the center of origin for maize and a major center of maize genetic diversity (Mesoamerica) (Doebley, 2004; Matsuoka et al., 2002). We interviewed farmers as a means to document their perspectives and obtain data in a relatively short time for preliminary analysis of the issues (as has been done in a number of other studies de Groote et al., 2005; Huang et al., 2005; Yang et al., 2005). Unlike other studies, however, we documented farmers' evaluation of transgenesis *per se*, and some forms of potential harm that could result from TGVs using scenarios. Our goal is to contribute to understanding potential effects of TGVs in TBAS, especially from farmers' perspectives, to improve the RMP and thus decisions about TGV use, control and future development. This methodology could be used by national scientists and local researchers to document and understand farmers' perspectives, and to begin to include these in the discussion.

RESULTS

Descriptions of farmers and farms included in this study are given in Tables 2a and 2b. The traditional and modern Guatemalan communities contrasted significantly for many of the variables included in this study, communities within Mexico and Cuba less so. Overall, the more traditional communities in each country planted fewer hectares of maize distributed over a greater number of fields, with a greater number of maize varieties, all of which make them less similar to industrial agricultural

Table 2b. Characteristics of farms included in study (average and standard deviation unless otherwise indicated).

Location (*n*)	Number of farm inputs[1,2]	Ha maize[2]	Fields maize[2]	Ha/field[2]	Maize varieties[2]	Sow FVs% (frequency)[3]	Have sown MVs% (frequency)[3]
Cuba (114)	**2.2 (35.1)**	**1.14* (1.13)**	**1.71 (0.93)**	**0.73* (0.77)**	**1.16* (0.37)**	**98.25 (112)**	**35.96 (41)***
La Palma, Pinar del Río (T) (56)	2.2 (35.7)b	0.57 (0.37)c	1.59 (0.76)bc	0.41 (0.30)c	1.25 (0.44)b	100.00 (56)	19.64 (11)
Mayorquín, Holguin (M) (58)	2.2 (34.8)b	1.70 (1.33)cd	1.83 (1.06)bc	1.05 (0.94)c	1.07 (0.26)b	96.55 (56)	51.72 (30)*
Guatemala (110)	**2.76* (46.4)**	**2.61* (3.94)**	**1.65* (0.92)**	**2.13* (3.32)**	**1.67* (0.81)**	**50.91 (56)***	**53.64 (59)***
El Rejón, Sacatepequez (T) (55)	1.6 (40.4)c	0.43 (0.21)d	2.05 (1.06)b	0.24 (0.16)c	2.11 (0.88)a	96.36 (53)	14.55 (8)
La Máquina, Suchitepequez (M) (55)	3.9 (11.8)a	4.79 (4.64)a	1.24 (0.51)c	4.06 (3.87)a	1.24 (0.43)b	5.45 (3)	92.73 (51)
México (110)	**1.3* (80.4)**	**2.96 (2.23)**	**2.45* (1.97)**	**1.70* (1.41)**	**1.50* (0.74)**	**99.09 (109)**	**24.55 (27)***
Santa Inez Yatzeche, Oaxaca (T) (55)	1.6 (62.6)c	2.65 (2.58)bc	3.62 (2.15)a	0.67 (0.27)c	1.96 (0.79)a	100.00 (55)	1.82 (1)
Comitancillo, Oaxaca (M) (55)	0.9 (96.3)d	3.27 (1.78)b	1.27 (0.65)c	2.72 (1.33)b	1.04 (0.19)b	98.18 (54)	47.27 (26)
Total (334)	**2.1 (58.0)**	**2.23 (2.79)**	**1.93 (1.41)**	**1.51 (2.19)**	**1.44 (0.70)**	**82.93 (277)**	**38.02 (127)**

[1] Of five possible: commercial fertilizer, herbicides, pesticides, grain storage pesticides.
[2] Means with the same letter not significantly different, Tukey's studentized range, $P < 0.05$.
[3] Includes households growing other varieties in addition.
* Significant difference between communities in same country, t-test for continuous variables. χ^2 test of independence or Fisher's exact test for categorical variables, $P < 0.05$.

systems than the more modern communities. In Guatemala and Cuba, more farmers in traditional communities planted FVs, but in Mexico nearly all farmers in both communities planted FVs. However, in addition to variation between traditional and modern communities, there was substantial variation within these classes. There was also substantial variation within and between countries. Although interviews were often conducted with families, 87–100% of primary respondents in each community were male.

Potential for unintended exposure

Data were collected to determine the potential for unintended exposure to transgenes *via* seed, grain or pollen, based on the current status of transgenic maize in all three countries — not authorized for commercial production — as well as potential if it were authorized in the future.

Seed systems

Although a majority of farmers have obtained maize seed off-farm (Tab. 3), the frequency with which they do so indicates the overall importance of farm-saved seed. There was much variation in off-farm seed acquisition, with 92% in the community with the most industrial agricultural system (La Máquina, Guatemala) obtaining seed off-farm every year compared with 0% in the traditional community in that same country. For off-farm seed, average distance from source to farm was short (11.5 km), with some spectacular exceptions, such as the

Table 3. Seed systems. Percent (number), unless otherwise indicated.

Location (*n*)	Of all interviewed, have acquired maize seed off farm in last 10 years	Of those getting off farm seed: Frequency of acquisition			Of those getting off farm seed: Source of seed				Of all interviewed, yearly off-farm maize seed solely from formal system	Distance (km) for off farm seed acquisition	
		Rarely	Occasionally	Yearly	Family, neighbors	Local market	Project	Agric. store		Average (Standard deviation)	Max.
Cuba (114)	**64.9 (74)**	**33.8 (25)***	**37.8 (28)**	**28.4 (21/74)**	**63.5 (47)***	**0.0**	**4.1 (3)**	**39.2 (29)***	**7.9 (9)***	**25.66 (126.58)**	**900.00**
La Palma, Pinar del Río (T) (56)	62.5 (35)	40.0 (14)	31.4 (11)	28.6 (10/35)	85.7 (30)	0.0	8.6 (3)	20.0 (7)	1.8 (1)	48.49 (177.21)	900.00
Mayorquín, Holguin (M) (58)	69.6 (39)	28.2 (11)	43.6 (17)	28.2 (11/39)	43.6 (17)	0.0	0.0	56.4 (22)	13.8 (8)	2.84 (2.63)	9.00
Guatemala (110)	**77.3 (85)**	**18.8 (16)***	**22.4 (19)***	**58.8 (50)***	**38.8 (33)***	**0.0**	**0.0**	**72.9 (62)***	**44.6 (49)***	**9.97 (10.28)**	**35.00**
El Rejón, Sacatepequez (T) (55)	56.4 (31)	48.4 (15)	51.6 (16)	0.0	93.6 (29)	0.0	0.0	29.0 (9)	0.0	2.79 (6.14)	17.00
La Máquina, Suchitepequez (M) (55)	98.2 (54)	1.9 (1)	5.7 (3)	92.6 (50)	7.4 (4)	0.0	0.0	98.2 (53)	89.1 (49)	14.59 (9.76)	35.00
México (110)	**84.56 (93)***	**9.7 (9)***	**74.2 (69)**	**16.1 (15)**	**77.4 (72)***	**26.9 (25)***	**1.1 (1)**	**15.1 (14)**	**0.0**	**3.33 (4.87)**	**20.00**
Santa Inez Yatzeche, Oaxaca (T) (55)	72.7 (40)	20.0 (8)	70.0 (28)	10.0 (4)	52.5 (21)	57.5 (23)	0.0	20.0 (8)	0.0	4.96 (4.55)	20.00
Comitancillo, Oaxaca (M) (55)	96.4 (53)	1.9 (1)	77.4 (41)	20.8 (11)	96.2 (51)	3.8 (2)	1.9 (1)	11.3 (6)	0.0	1.87 (4.70)	15.00
Total (334)	**75.5 (252)**	**19.8 (50)**	**46.0 (116)**	**34.1 (86)**	**60.3 (152)**	**9.9 (25)**	**1.6 (4)**	**41.7 (105)**	**17.4 (58)**	**11.49 (65.78)**	**900.00**

* Significant difference between communities in same country, χ^2 test of independence or Fisher's exact test, $P < 0.05$.

Table 4. Maize grain acquisition and planting. Percent (number).

Location (n)	Obtained maize grain off farm for eating in last 10 years	Of all those obtaining maize grain off-farm (n = 138)		Of those obtaining maize grain *only* from potential sources of GE maize (n = 20)[2], have sown that grain
		Obtained from potential sources of TGV maize[1]	Have sown grain obtained	
Cuba (114)	**16.8 (19/113)**	**21.1 (4/19)**	**15.8 (3/19)**	**0.0 (0/3)**
La Palma, Pinar del Río (T) (56)	16.4 (9/55)	33.3 (3/9)	11.1 (1/9)	0.0 (0/2)
Mayorquín, Holguin (M) (58)	17.2 (10/58)	10 (1/10)	20.0 (2/10)	0.0 (0/1)
Guatemala (110)	**36.3 (40/110)***	**22.5 (9/40)**	**17.5 (7/40)**	**11.1 (1/9)**
El Rejón, Sacatepequez (T) (55)	60.0 (33/55)	24.2 (8/33)	12.1 (4/33)	12.5 (1/8)
La Máquina, Suchitepequez (M) (55)	12.7 (7/55)	14.3 (1/7)	42.9 (3/7)	0.00 (0/1)
México (110)	**71.8 (79/110)**	**13.9 (11/79)**	**34.2 (27/79)***	**12.5 (1/8)**
Santa Inez Yatzeche, Oaxaca (T) (55)	74.6 (41/55)	17.1 (7/41)	9.8 (4/41)	0.0 (0/7)
Comitancillo, Oaxaca (M) (55)	69.1 (38/55)	10.5 (4/38)	60.5 (23/38)	100 (1/1)
Total (333)	**41.4 (138/333)**	**17.4 (24/138)**	**26.8 (37/138)**	**10 (2/20)**

[1] Includes those obtaining grain from potential source of TGV maize grain and other sources.
[2] Does not include those obtaining grain from potential source of TGV maize grain and other sources.
*Significant difference between communities in same country, χ^2 test of independence or Fisher's exact test, $P < 0.05$.

movement of seed more than 900 km from eastern Cuba to La Palma *via* a relative. Seed movement *via* migrants was not included in these calculations (or in Tab. 3) because farmers see this as a one-time experiment, and do not mention it when asked about seed sources. Migrant family or community members brought seed that was sown by 6% (18/322) of farmers, three of these (1%) involved international movement: Angola to Cuba, US to Guatemala, Guatemala to Mexico.

Most off-farm seed came from the informal distribution system, *i.e.* family and neighbors or markets (local and regional markets as well as itinerant seed vendors), but a large proportion was from the formal distribution system (government and private agricultural stores and projects). While the informal system may be a source of TGVs, in all six communities, agricultural stores sell only seed from the formal system (MVs), and would be the initial source of TGV seed if approved in the future. La Máquina, Guatemala had the highest yearly off-farm seed procurement (92.6%), and also the largest proportion of this solely from the formal system (89.1%).

Seed vs. grain distinction

Sowing maize seed acquired off-farm as grain was not unusual (Tab. 4). However, for households acquiring grain solely from the most likely sources of TGV maize (private and government stores and institutions), only 11.0% (2/19) sowed that grain.

Structure and scale of production

The average number of maize fields per household was 1.93, with an average field size of 1.51 ha. Many small maize fields provide ample opportunities for pollen movement among fields of different households (Tab. 2b), presenting a challenge to containment.

Farmers' evaluation of potential harm

Transgenesis per se

A majority of farmers in most communities felt transgenesis *per se* was acceptable (*i.e.* chose responses

Table 5. Farmers' opinions about transgenesis *per se* and responses to scenarios. Percent (number).

Location (*n*)	Transgenesis *per se* is unacceptable (*i.e.* chose the response "bad")	Scenario 1. Yield stability and V_E: prefer stable variety	Scenario 2. Yield stability, seed cost and source. Prefer stable variety (X) over new variety (Z) when[1]	
			Z costs 2x > X	Cost Z = cost X
Cuba (114)	**42.2 (46/109)***	**61.4 (70/110)[2]**	–	–
La Palma, Pinar del Río (T) (56)	28.3 (15/53)	58.9 (33/56)	–	–
Mayorquín, Holguin (M) (58)	55.4 (31/56)	63.8 (37/58)[2]	–	–
Guatemala (110)	**17.4 (19/109)***	**51.9 (56/109)**	**82.7 (91/110)*[2]**	**75.9(83/109)*[2]**
El Rejón, Sacatepequez (T) (55)	33.3 (18/54)	87.0 (47/54)[2]	92.7 (51/55)[2]	90.7 (49/54)[2]
La Máquina, Suchitepequez (M) (55)	1.8 (1/55)	16.7 (9/55)[3]	72.7 (40/54)[2]	61.1 (34/55)
México (110)	**42.7 (47/110)**	**76.4 (84/110)[2]**	**89.9 (98/109)[2]**	**89.5 (94/105)[2]**
Santa Inez Yatzeche, Oaxaca (T) (55)	50.9 (28/55)	76.4 (42/55) [2]	85.5 (47/55)[2]	84.6 (47/55)[2]
Comitancillo, Oaxaca (M) (55)	34.5 (19/55)	76.4 (42/55)[2]	94.4 (51/54)[2]	94.3 (51/54)[2]
Total (334)	**34.1 (112/328)**	**63.3 (210/333)[2]**	**86.3 (219/232)[2]**	**82.6 (178/216)[2]**

[1] Data for Cuba not available.
[2] Scenarios 1 and 2: significantly more prefer stable variety, χ^2 test of goodness of fit, $P < 0.05$.
[3] Scenario 1: significantly more prefer responsive variety, χ^2 test of goodness of fit, $P < 0.05$.
* Significant difference between communities in same country. χ^2 test of independence, $P < 0.05$.

other than "bad"), based on the description presented to them (see Methods). However, this varied substantially across communities and significantly between the two Cuban communities, and between the two Guatemalan communities (Tab. 5), perhaps due to different cultural values and experiences with the products of formal agricultural research.

Yield vs. yield stability in response to V_E

In this scenario farmers chose between varieties with high yield and yield stability in response to variable rainfall. Overall, more farmers preferred the stable variety (Tab. 5). The most notable exception was La Máquina, Guatemala, where over 83% preferred the responsive variety.

Yield vs. yield stability in a hypothetical TGV

This scenario addressed the question of whether possible changes in yield stability and seed procurement due to the evolution of pest resistance to a hypothetical *Bt* transgene in maize were considered harmful by TBAS farmers. Significantly more farmers preferred the more stable variety (X). Local variation was present however — in Guatemala the frequency of farmers choosing each variety differed significantly between communities. In La Máquina a large majority favored the responsive variety, perhaps because of their strong market orientation. Distribution of responses to a follow-up question asking about preferences if seed of both varieties had the same price did not change substantially (Tab. 5).

Farmers' evaluation of maize varieties: ranking exercise

The purpose of the ranking exercises was to investigate farmers' evaluations of transgenic maize in relation to different genetic backgrounds, and in comparison to nontransgenic maize.

Rankings of individual maize varieties

We first fit a basic B-T model (see Methods), and obtained estimates of rank value. These produced the preference orderings (FV, MV, TGFV, TGMV) for sowing: 0.47, 0.23, 0.19, 0.10; and for eating: 0.87, 0.09, 0.03, 0.01. The preferences show a clear departure from a null hypothesis of equivalent preferences – (0.25, 0.25, 0.25, 0.25) – with a strong preference for the FV, especially for eating.

However, the assumption of the null hypothesis under the basic B-T model is that preferences are homogeneous over all subjects. The extended B-T model allows testing for differences among countries, communities, farm size, and other subject attributes. The null hypothesis assumes orders and magnitudes for all subgroups to be equivalent to those observed for the pooled basic B-T model. We discuss two analyses using the basic, then the extended B-T model.

The first model uses all of the data and allows for variation in the ranking orders by country, community type, farm size, and two questions asked of farmers. Results for both sowing and eating (Tab. 6) indicate significant variation among preference magnitudes over the categories of these covariates. The farmer's country has a strong impact on sowing preferences but relatively less for eating preferences. Similarly, community type (traditional versus modern), and farm size (small: ha < 2.5; medium: 2.5 < ha < 5.0; large: ha > 5.0) have statistically significant patterns but the ranking value and degree of significance differs between sowing and eating preferences. Finally, farmers' sowing preferences are significantly affected by what they think about transgenesis *per se* (covariate THINK), but not their eating preferences. That is, a negative opinion about transgenesis *per se* is associated with higher ranking values for FV and MVs for sowing, but among both those with negative and positive opinions about transgenesis *per se* there is no significant difference in ranks for eating — all strongly prefer FVs. This first set of extended model results rejects the basic B-T model and thus the null hypothesis.

To determine if these results still obscured underlying variation in effects of subject covariates by country, a second set of models was fitted to country-specific data for sowing (Tab. 7) and eating (Tab. 8) preferences. Results strongly support the use of country specific models since the significance and magnitude of subject covariates vary strongly by country. For example, for sowing significant covariates were farm size in Mexico (smaller farm size associated with a higher value for FVs); opinions about transgenesis *per se* in Cuba (positive opinion about transgenesis associated with higher values for transgenic varieties); and community type in Guatemala (both magnitude and order of ranks differed between communities, contrasting with Mexico and Cuba).

Rankings as patterns

For both sowing and eating most farmer rankings (92.5 and 95.5%, respectively) fell among four patterns (see Methods), significantly more than in all other eight possible patterns combined (Tab. 9). A majority avoided TGVs for both sowing and eating with the exception of La Palma, Cuba. Overall 14% and 20% of respondents refused to include the TGVs in their rankings for sowing and eating, respectively.

DISCUSSION

The number of communities and farmers on which our analysis is based is relatively small, and conclusions must therefore be made cautiously, despite our effort to select communities in each country that represented contrasting modern and traditional agricultural systems, and to sample farmers in those communities randomly. As our data indicate, distinct combinations of variables characterize communities in ways that can make generalizations inappropriate, including 'traditional' and 'modern' agriculture. However, our results also indicate qualities of TBAS environments, crop genotypes, and society and culture that differ from industrial systems in ways important for TBAS functioning and relevant to the risk management process for TGVs.

Potential for unintended exposure.

Opportunities for exposure *via* transgene flow now and in the future, including those not commonly assumed present in industrialized agricultural systems, have been documented (Tabs. 2a, 2b, 3 and 4). Many of these opportunities represent strategies and processes critical for the functioning of TBAS where food production, storage and consumption, seed multiplication, crop improvement and genetic resources conservation are integrated within the same household or community.

Seed systems

MV genes may be present in TBAS *via* purchase, exchange or gifts of MVs, farmer-saved seed of F_1's or subsequent generations of FV × MV hybrids. We presumed the same sources of exposure to TGV seed if TGVs are approved in the future. Obtaining seed on-farm or through the informal distribution system reduces the possibility of initial transgene flow *via* TGV seeds should those be approved. But it also means that formal sector seed sales would not be a means of controlling transgene flow, for example in managing evolution of resistance in pest populations, as presumed in industrial systems (EPA, 1998: 39ff). Once transgenes are present in local crop populations, on-farm seed saving and informal seed

Table 6. Relative rank value of four maize varieties for sowing and eating based on farmers' ranking exercise[1].

	Sowing				Eating			
	Estimate	Std. Error	Pr(>|z|)	Signif.	Estimate	Std. Error	Pr(>|z|)	Signif.
FV	4.73	0.27	< 2e-16	***	3.70	0.32	< 2e-16	***
MV	2.54	0.20	< 2e-16	***	1.96	0.22	< 2e-16	***
TGFV	1.65	0.19	< 2e-16	***	1.31	0.20	0.00	***
TGMV	–	–	–		–	–	–	
FV:CTRY2	–2.17	0.21	< 2e-16	***	–1.93	0.35	0.00	***
FV: CTRY 3	–2.25	0.19	< 2e-16	***	–0.73	0.34	0.03	*
MV: CTRY 2	–1.24	0.17	0.00	***	–1.16	0.25	0.00	***
MV: CTRY 3	–0.99	0.15	0.00	***	–0.27	0.24	0.26	
TGFV: CTRY 2	–0.63	0.15	0.00	***	–0.68	0.23	0.00	**
TGFV: CTRY 3	–0.76	0.15	0.00	***	–0.17	0.22	0.44	
TGMV: CTRY 2	–	–	–		–	–	–	
TGMV: CTRY 3	–	–	–		–	–	–	
FV:COMM	–0.92	0.13	0.00	***	0.62	0.26	0.02	*
MV:COMM	–0.33	0.11	0.00	**	0.55	0.19	0.00	**
TGFV:COMM	–0.65	0.11	0.00	***	0.06	0.18	0.72	
TGMV:COMM	–	–	–		–	–	–	
FV:FARM2	–0.46	0.16	0.00	**	–0.53	0.42	0.20	
FV:FARM3	–1.01	0.20	0.00	***	–2.05	0.32	0.00	***
MV:FARM2	–0.29	0.13	0.02	*	–0.49	0.29	0.09	–
MV:FARM3	–0.41	0.16	0.01	*	–1.40	0.26	0.00	***
TGFV:FARM2	–	–	–		–0.18	0.27	0.49	
TGFV:FARM3	–	–	–		–0.53	0.25	0.04	*
TGMV:FARM2	–	–	–		–	–	–	
TGMV:FARM3	–	–	–		–	–	–	
FV:HEAR	–0.31	0.17	0.07	–	–	–	–	
MV:HEAR	–0.26	0.14	0.07	–	–	–	–	
TGFV:HEAR	–	–	–		–	–	–	
TGMV:HEAR	–	–	–		–	–	–	
FV:THINK	–1.80	0.19	< 2e-16	***	–	–	–	
MV:THINK	–1.17	0.15	0.00	***	–	–	–	
TGFV:THINK	–0.47	0.15	0.00	**	–	–	–	
TGMV:THINK	–	–	–		–	–	–	
Null deviance	3451				5316			
Null DF.	479				719			
Resid. deviance	391				226			
Resid. DF.	219				456			
AIC:	1944				1750			

[1] Empty cells indicate non significant covariate and model reverts from extended back to the basic B-T analysis.
FV = farmer variety, MV = modern variety, TGFV = transgenic farmer variety, TGMV = transgenic modern variety.
Subject specific covariates and states in extended models: CTRY = country, CTRY2 = Cuba, CTRY3 = Guatemala; COMM = modern community; FARM = farm size, FARM2 = 2.5 < ha < 5.0, FARM3 = ha > 5.0; HEAR = have heard of transgenic maize; THINK = transgenesis *per se* is acceptable.
Covariate states for basic model: CTRY = Mexico; COMM = traditional; FARM = ha < 2.5; HEAR = have not heard of transgenic maize; THINK = transgenesis *per se* is unacceptable.
*, **, *** Significance at 0.05, 0.01 and 0.001, respectively.

Table 7. Farmer rankings of maize varieties for sowing × country and subject covariates[1].

	Mexico				Cuba				Guatemala			
	Estimate	Std. Error	Pr(>|z|)	Signif.	Estimate	Std. Error	Pr(>|z|)	Signif.	Estimate	Std. Error	Pr(>|z|)	Signif.
FV	3.66	0.44	< 2e-16	***	1.62	0.24	0.00	***	3.25	0.47	0.00	***
MV	1.55	0.20	0.00	***	0.91	0.20	0.00	***	1.97	0.39	0.00	***
TGFV	1.13	0.16	0.00	***	0.54	0.19	0.00	**	1.29	0.36	0.00	***
TGMV	–	–	–		–	–	–		–	–	–	
FV:COMM	–0.95	0.33	0.00	**	0.39	0.18	0.04	*	–3.22	0.26	< 2e-16	***
MV:COMM	–0.46	0.18	0.01	**	0.42	0.17	0.01	*	–1.95	0.23	< 2e-16	***
TFV:COMM					–0.10	0.17	0.55		–1.37	0.22	0.00	***
TMV:COMM					–	–	–		–	–	–	
FV:FARM2	0.62	0.38	0.10		–	–	–		–	–	–	
FV:FARM3	–1.18	0.33	0.00	***	–	–	–		–	–	–	
MV:FARM2	0.25	0.21	0.25		–	–	–		–	–	–	
MV:FARM3	–0.53	0.26	0.04	*	–	–	–		–	–	–	
TGFV:FARM2	–	–	–		–	–	–		–	–	–	
TGFV:FARM3	–	–	–		–	–	–		–	–	–	
TGMV:FARM2	–	–	–		–	–	–		–	–	–	
TGMV:FARM3	–	–	–		–	–	–		–	–	–	
FV:HEAR	–	–	–		–	–	–		–	–	–	
MV:HEAR	–	–	–		–	–	–		–	–	–	
TGFV:HEAR	–	–	–		–	–	–		–	–	–	
TGMV:HEAR	–	–	–		–	–	–		–	–	–	
FV:THINK	–0.94	0.37	0.01	*	–1.42	0.24	0.00	***	–1.37	0.48	0.00	**
MV:THINK	–0.46	0.20	0.02	*	–1.15	0.21	0.00	***	–0.66	0.41	0.11	
TGFV:THINK	–	–	–		–0.17	0.20	0.40		–0.34	0.38	0.38	
TGMV:THINK	–	–	–		–	–	–		–	–	–	
Null deviance	1195				1122				1015			
Null DF.	215				143				119			
Resid. deviance	67	167			50				91			
Resid. DF.	97	105			63				51			
AIC:	720	752			530				529			

[1] Empty cells indicate non significant covariate and model reverts from extended back to the basic B-T analysis.
FV = farmer variety, MV = modern variety, TGFV = transgenic farmer variety, TGMV = transgenic modern variety.
Subject specific covariates and states in extended models: CTRY = country, CTRY2 = Cuba, CTRY3 = Guatemala; COMM = modern community; FARM = farm size, FARM2 = 2.5 < ha < 5.0, FARM3 = ha > 5.0; HEAR = have heard of transgenic maize; THINK = transgenesis per se is acceptable.
Covariate states for basic model: CTRY = Mexico; COMM = traditional; FARM = ha < 2.5; HEAR = have not heard of transgenic maize; THINK = transgenesis *per se* is unacceptable.
*, **, *** Significance at 0.05, 0.01 and 0.001, respectively.

Table 8. Farmer rankings of maize varieties for eating × country and subject covariates[1].

	Mexico				Cuba				Guatemala			
	Estimate	Std. Error	Pr(>|z|)	Signif.	Estimate	Std. Error	Pr(>|z|)	Signif.	Estimate	Std. Error	Pr(>|z|)	Signif.
FV	3.33	0.26	< 2e-16	***	1.61	0.17	< 2e-16	***	3.55	0.32	< 2e-16	***
MV	1.75	0.17	< 2e-16	***	0.67	0.13	0.00	***	2.08	0.24	< 2e-16	***
TGFV	1.14	0.16	0.00	***	0.63	0.13	0.00	***	1.31	0.21	0.00	***
TGMV	–	–	–		–	–	–		–	–	–	
TIE	–	–	–		–1.78	0.25	0.00	***	–4.28	1.01	0.00	***
FV:COMM	–	–	–		1.08	0.34	0.00	**	–	–	–	
MV:COMM	–	–	–		0.96	0.27	0.00	***	–	–	–	
TGFV:COMM	–	–	–		0.09	0.25	0.71		–	–	–	
TGMV:COMM	–	–	–		–	–	–		–	–	–	
TIE:COMM	–	–	–		0.30	0.40	0.45		–	–	–	
FV:FARM2	–	–	–		–0.94	0.91	0.30		0.27	0.63	0.66	
FV:FARM3	–	–	–		–2.38	0.54	0.00	***	–1.95	0.43	0.00	***
MV:FARM2	–	–	–		–1.41	0.67	0.03	*	0.44	0.50	0.38	
MV:FARM3	–	–	–		–1.51	0.50	0.00	**	–1.30	0.34	0.00	***
TGFV:FARM2	–	–	–		–0.29	0.71	0.69		0.17	0.44	0.71	
TGFV:FARM3	–	–	–		–1.00	0.58	0.08	–	–0.68	0.32	0.03	*
TGMV:FARM2	–	–	–		–	–	–		–	–	–	
TGMV:FARM3	–	–	–		–	–	–		–	–	–	
TIE:FARM2	–	–	–		2.03	0.68	0.00	**	1.43	1.44	0.32	
TIE:FARM3	–	–	–		–16.18	1514.00	0.99		–16.49	4017.64	1.00	
FV:HEAR	–	–	–		–	–	–		–1.36	0.43	0.00	**
MV:HEAR	–	–	–		–	–	–		–1.04	0.36	0.00	**
TGFV:HEAR	–	–	–		–	–	–		–0.44	0.35	0.21	
TGMV:HEAR	–	–	–		–	–	–		–	–	–	
TIE:HEAR	–	–	–		–	–	–		–15.89	2286.14	0.99	
FV:THINK	–	–	–		–	–	–		–	–	–	
MV:THINK	–	–	–		–	–	–		–	–	–	
TGFV:THINK	–	–	–		–	–	–		–	–	–	
TGMV:THINK	–	–	–		–	–	–		–	–	–	
TIE:THINK	–	–	–		–	–	–		–	–	–	
Null deviance	1280				1697				1707			
Null df.	215				215				179			
Resid. deviance	52				93				48			
Resid. Df.	105				128				104			
AIC:	657				599				482			

[1] Empty cells indicate non significant covariate and model reverts from extended back to the basic B-T analysis.
FV = farmer variety, MV = modern variety, TGFV = transgenic farmer variety, TGMV = transgenic modern variety.
Subject specific covariates and states in extended models: CTRY = country, CTRY2 = Cuba, CTRY3 = Guatemala; COMM = modern community; FARM = farm size, FARM2 = 2.5 < ha < 5.0, FARM3 = ha > 5.0; HEAR = have heard of transgenic maize; THINK = transgenesis *per se* is acceptable.
Covariate states for basic model: CTRY = Mexico; COMM = traditional; FARM = ha < 2.5; HEAR = have not heard of transgenic maize; THINK = transgenesis *per se* is unacceptable.
*, **, *** Significance at 0.05, 0.01 and 0.001, respectively.

Table 9. Patterns of farmers' preference ranking of maize varieties for sowing and eating[1]. Percent (number).

Location (*n*)	Sowing					Eating				
	Pro FV	Pro MV	Pro TGV	Avoid TGV	All other patterns	Pro FV	Pro MV	Pro TGV	Avoid TGV	All other patterns
Cuba (114)	**21.1 (24)**	**2.6 (3)**	**16.7 (19)**	**49.1 (56)**	**10.5 (12)**	**22.8 (26)**	**3.5 (4)**	**3.5 (4)**	**64.0 (73)***	**6.0 (7)**
La Palma, Pinar del Río (T) (56)	33.9 (19)	1.8 (1)	23.2 (13)	32.1 (18)	8.9 (5)	37.5 (21)	5.4 (3)	5.4 (3)	50.0 (28)	1.8 (1)
Mayorquín, Holguin (M) (58)	8.6 (5)	3.4 (2)	10.3 (6)	65.5 (38)*	12.1 (7)	8.6 (5)	1.7 (1)	1.7 (1)	77.6 (45)*	10.4 (6)
Guatemala (110)	**7.3 (8)**	**6.4 (7)**	**35.5 (39)**	**43.6 (48)**	**7.3 (8)**	**17.3 (19)**	**1.8 (2)**	**1.8 (2)**	**76.4 (84)***	**2.7 (3)**
El Rejón, Sacatepequez (T) (55)	14.5 (8)	0	3.6 (2)	76.4 (42)*	2.7 (3)	16.4 (9)	1.8 (1)	0	80 (44)*	1.8 (1)
La Máquina, Suchitepequez (M) (55)	0	12.7 (7)	67.3 (37)*	10.9 (6)	9.0 (5)	18.2 (10)	1.8 (1)	3.6 (2)	72.7 (40)*	3.6 (2)
México (110)	**27.3 (30)**	**0**	**1.8 (2)**	**66.4 (73)***	**4.5 (5)**	**21.8 (24)**	**0**	**0**	**73.6 (81)***	**4.5 (5)**
Santa Inez Yatzeche, Oaxaca (T) (55)	38.2 (21)	0	0	61.8 (34)	0	27.3 (15)	0	0	70.9 (39)*	1.8 (1)
Comitancillo, Oaxaca (M) (55)	16.4 (9)	0	3.6 (2)	70.9 (39)*	9.1 (5)	16.4 (9)	0	0	76.4 (42)*	7.2 (4)
Total (334)	**18.6 (62)**	**3.0 (10)**	**18.0 (60)**	**53.0 (177)**	**7.5 (25)**	**20.7 (69)**	**1.8 (6)**	**1.8 (6)**	**71.3 (238)***	**4.5 (15)**

[1] First two choices in ranking, include in any order: Pro FV = FV and TGFV, Pro MV = MV and TGMV, Pro TGV = TGFV and TGMV, Avoid TGV = FV and MV. FV = farmer variety, MV = modern variety, TGFV = transgenic farmer variety, TGMV = transgenic modern variety.
* Significantly greater frequency than other patterns at that location. χ^2 test of independence, $P < 0.05$.

networks may contribute to their persistence (Tab. 3). Farmers in this study can be sorted into three groups according to their seed systems: (a) those who never acquire seed off-farm (24.5%) and thus are least likely to be affected by transgenes *via* seed flow; (b) those who acquire seed off-farm but who may also save their own seed (58.1%) and so are more likely to be affected by transgene seed flow, but are insufficiently incorporated into the formal system for it to provide a control mechanism; and (c) those who acquire seed off-farm annually *only* from the formal system (17.4%), which could then function as a control point.

Seed vs. grain distinction

Seed and grain are distinct products in industrialized agriculture, differences include their genotypes, who grows them, and how they are treated post harvest, and distributed (Fernandez-Cornejo, 2004). This distinction is not present in TBAS (Morris, 1998) where there is concern over maize grain as a source of transgene flow (*e.g.* Mora, 2005). In TBAS, seed and grain are most often taken from the same population, with seed selected post-harvest based on criteria such as kernel density, ear and kernel size and sanitation (Soleri et al., 2000). We found few households (24) obtained grain from potential sources of TGV maize. However; another study in two communities in the Central Valleys of Oaxaca found 63% (37/59) of households acquire grain from potential sources of TGV maize, and 32% (12/37) sowed that grain (Aragón Cuevas et al., n.d.). Unintentional seed movement may occur when grain or seed falls from transport vehicles and sacks and grows, creating the potential for pollen flow. Many farmers in each community (50–98%, data not shown) said they would leave a, volunteer maize plant of unknown origin to grow next to their fields.

The seed procurement practices we documented provide viable planting seed to farmers not served by the formal improvement and distribution systems. This includes obtaining and experimenting with new material, an approach TBAS farmers often favor over selection within extant populations, especially for allogamous crops like maize (Louette and Smale, 2000; Soleri et al., 2000).

Structure and scale of production

Seed saving reduces the possibility of exposure to novel genes *via* seeds but not pollen (Ellstrand, 2003; Messeguer, 2003). Hybridization in maize has been documented up to 37 m for transgenic pollen (maximum distance measured) (Chilcutt and Tabashnik, 2004; Ma et al., 2004) and up to 200 m for conventional maize pollen (Luna et al., 2001), although also reported 800 m from pollen source (Eastham and Sweet, 2002). Probabilities of hybridization decline rapidly with distance from pollen source, but longer distance hybridizations may remain "undetected because they are unexpected" including due to sampling design (Klinger, 2002: 11).

Pollen mediated, unintentional gene flow in industrial systems is a challenge to acceptable use of TGVs and methods of containment, or at least confinement, are being investigated (Daniell, 2002; NRC, 2004; Snow et al., 2005). In addition to the possible cultural, economic, intellectual property and agronomic implications of unintentional transgene flow to FVs, it may also compromise the efficacy of refuge strategies for slowing the evolution of resistance among pest populations controlled by pesticidal TGVs (Chilcutt and Tabashnik, 2004; Fitt, 2004; Gould and Cohen, 2000: 244). This may be particularly true with the scale and spatial distribution of maize fields in many TBAS. While the average size of maize grain farms in the USA in 2003 was 79.2 ha (USDA NASS, 2004), in Oaxaca, Mexico over 76% of maize farms are smaller than 5 ha (INEGI, 2001). Based on the average number of fields per household in our sample there are approximately 753 maize fields in Santa Inez Yatzeche (calculated from survey data and INEGI, 1996). The large number of small maize fields would need to be monitored if crop refuges were required, if it were physically and economically feasible to establish them. Therefore, managing evolution of pest resistance will need different strategies in TBAS (Fitt, 2004; Gould and Cohen, 2000). However, while most discussion about transgene flow in industrial systems and TBAS has assumed that minimization is the goal, there is evidence that gene flow in TBAS is extensive and critical for the genetic health of local maize populations (Pressoir and Berthaud, 2004). Thus, it will be necessary to consider how reducing gene flow in the interest of containing transgenes may impact the viability of these crop metapopulations that are characterized by gene flow and local selection pressures.

Farmers' evaluation of potential harm

The net benefit to TBAS farmers from TGVs as stated by TGV proponents (*e.g.*, www.isaaa.org/, www.agbioworld.org/, www.monsanto.com/monsanto/layout/our_pledge/global_challenges/food_security/reaching.asp), or the net harm stated by opponents (*e.g.*, www.greenpeace.org/international/campaigns/genetic-engineering), is rarely based on research directly with farmers. A major obstacle to conventional surveys is that many TBAS farmers are not aware of the existence of TGMVs, even when transgenes are present in their area. For example, in the state of Oaxaca the site of the transgenic "maize scandal", few of the farmers we interviewed had heard of transgenic maize (Tab. 2a).

Farmers' evaluation of transgenesis *per se* and potential consequences as depicted in our scenarios indicate that cultural harm is not a significant issue for this particular sample overall, but other forms of harm are.

Transgenesis per se

The evaluation of potential harm is complex. The most fundamental question is whether a technology (in this case interspecific gene transfer) is acceptable *per se*, regardless of its consequences. We refer to this as evaluation of cultural harm. For our research we defined perceived damage to the fundamental values and identity of a people as a group or personally, as cultural harm, which like all forms of harm, is subjective. The CEC (Commission for Environmental Cooperation of North America) reported that some Mexican communities and individuals find the presence of transgenes in Mexican maize landraces "an unacceptable risk to their traditional farming practices, and their cultural, symbolic, and spiritual value of maize" and that this "sense of harm is independent of its scientifically studied potential or actual impact upon human health, genetic diversity, and the environment" (CEC, 2004: 50). This opinion has been interpreted as unscientific by some, including the US government (CEC, 2004: 50).

In our study a minority of farmers found transgenesis *per se* in maize unacceptable (Tab. 5), many of them making the same comments heard often in the debate in the industrial world: "this is bad, unnatural", "not normal", "it violates the balance of nature". However, there was significant variation between communities. For example, recent experience in the two Cuban communities with the agricultural research system — positive in La Palma due to a new maize diversity and participatory maize breeding project, negative in Mayorquín due to perceived negative health consequences of agrochemical intensive production — may have contributed to the former having a more favorable attitude toward transgenesis. Some farmers in this study who found the idea of transgenesis *per se* in maize unacceptable may have given this response in part because they find the source (governmental or commercial system) untrustworthy. For example, some of the farmers in Mexico believed they have been used to test dangerous or unknown technologies (medicines, agricultural chemicals), to their detriment. For those who see the technology *per se* as unacceptable the consequences are irrelevant. If the technology *per se* is acceptable, then evaluation of other forms of potential harm will depend on the consequences of the technology (see Burgess and Walsh, 1998).

Yield vs. yield stability in response to V_E

A fundamental question in crop improvement for TBAS is whether high yield or yield stability is a more appropriate goal (Ceccarelli et al., 1994; Cleveland, 2001; Simmonds and Smartt, 1999), and is fundamentally related to perceptions of risk (Walker, 1989). Our goal was to understand farmers' evaluations of (a) yield *vs*. yield stability, and (b) of yield *vs*. yield stability including potential consequences of hypothetical maize TGVs. This first scenario we used depicted genotype by environment interaction in response to temporal variation in rainfall, in order to elicit farmer preference for yield *vs*. yield stability. Most farmers chose the variety with stable yields, as was found in a comparative study of farmers in four locations, with different crops (Soleri et al., 2002). Only in La Máquina, Guatemala were high yields preferred (see Tab. 5). In this study La Máquina is unique for its complete market integration – (100% of farmers sell their maize as compared to 47% in El Rejón, Guatemala, 52% in Oaxaca, Mexico, and 0% in Cuba), through which they immediately convert their harvest into cash. Those preferring the responsive maize often noted that the higher overall yield compensated for the bad years, whereas comments from those favoring the stable variety centered on the importance of it producing at least something every year.

Yield vs. yield stability in a hypothetical TGV

The second scenario is relevant to pesticidal transgenes introduced into FV backgrounds (intentionally or not), or locally appropriate TGMVs. This is not intended to depict current *Bt* maize varieties as none yet substantially control significant pests of the region such as fall armyworm (*Spodoptera frugiperda* L). The scenario assumes the hypothetical transgene offers protection from a major local pest, and when that protection is lost through evolution of resistance in the pest, the formal seed system is the only source for effective alternative TGVs.

Yield stability was preferred over high yield by most farmers, even in relatively modern TBAS. For example, coefficients of variation (CVs) of maize yields (calculated using triangulation of farmer estimates, Hardaker et al., 1997) averaged > 35% in the Oaxacan communities, and 28% and 18% in traditional and modern communities in Guatemala. La Máquina farmers' preference for high yield over yield stability for the first scenario did not persist in response to this second scenario. Yield instability was not preferred, even when differences in seed cost were eliminated, suggesting that yield decline over time due to evolution of resistance in pests, not actual yield as depicted in the first scenario, is perceived as harmful even in the most industrialized system in this study.

Farmers' evaluation of maize varieties: ranking exercises

Ranking individual varieties

Discussion of TGVs with TBAS farmers is easily confounded by their experience or assumptions about other varieties, including MVs, that are products of the formal crop improvement system. Transgenes may be introduced intentionally or unintentionally in TBAS, and in different genetic backgrounds. Intentional creation of transgenic maize varieties includes choice of genetic background by the formal crop improvement system. The cost of the multi-step process of obtaining stable insertion of a transgene into a background genotype without extensive undesirable linkage is not trivial (Goodman, 2004; Zhong, 2001), and limits the number and type of TGVs developed. Until now in maize, transgenes have been placed into MV backgrounds. Transgenes may move into maize FVs unintentionally as documented by some in maize in Mexico (Alvarez-Morales, 2002), or be intentionally inserted as planned in Kenya (Fitt, 2004: 224).

Farmers' ranking of varieties of maize identifies preferences including genetic backgrounds for improved varieties, and indicates that although open to new maize technology, farmers are cautious, particularly about maize for eating. In addition, the magnitude and even order of the ranking can vary significantly along with a number of farmer-specific characteristics within and between countries (Tabs. 6, 7 and 8). Farmers in the relatively

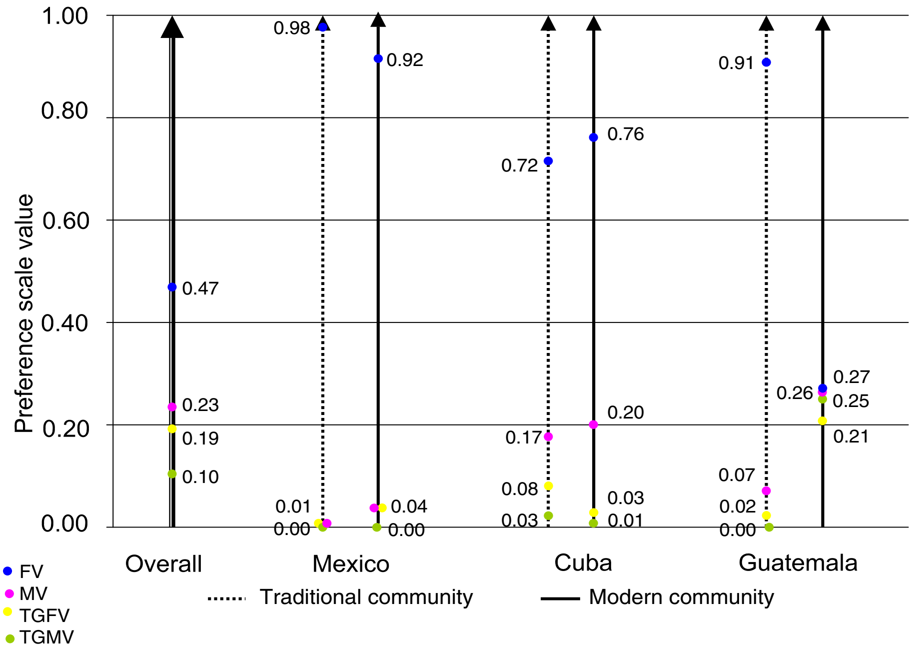

Figure 1. Farmer ranking preference scales: sowing × country and community type.

industrialized agricultural community of La Máquina, Guatemala were more accepting of TGV maize, and both magnitude and order of ranks differed between more modern and traditional Guatemalan communities, unlike those in Mexico and Cuba (Fig. 1). La Máquina farmers saw transgenic maize as another variety produced by the formal system on which they already rely. A corollary to this interpretation is that farmers in more traditional farming systems saw transgenic maize as another variety produced by the formal system, whose maize releases they have not widely accepted.

Overall, FVs were the preferred maize type for both sowing and eating. The ranking supported the scenario results — that farmers in all communities are open to experimentation, but cautious about possible consequences of TGVs. Rankings for sowing differ from those for eating, as seen in rank values (Tab. 6) and patterns (Tab. 9). In the one exception (La Máquina, Guatemala) the majority of farmers favored TGVs for sowing but avoided them for eating. Altogether, 14% and 20% of respondents refused to include the TGVs in their rankings for sowing and eating, respectively. These results suggest that most farmers prefer FVs as the starting point for improved varieties, including TGVs, for which decentralized breeding and collaboration between farmers and plant breeders will be important (Cleveland and Soleri, 2002). They can also be interpreted as indicating that the farmers who have not been served by the products of the formal maize improvement and seed production systems do not anticipate benefits for themselves from the latest technology generated by those systems.

As a whole, the results support rejecting the null hypothesis that farmer characteristics do not affect preferences, and support accepting the alternative that, for sowing, these are highly dependent on the country context. Eating preferences indicate general similarities among countries (relative order and significance), contrasting with sowing preferences in the structure of significant covariates (Tab. 8, Fig. 2). Indeed, the only data that conformed to the basic B-T model (no significant subject covariates) was rankings for eating by Mexican farmers — there is strong agreement among all Mexican farmers that the preferred maize type for eating is FV.

Rankings as patterns

Despite the individual high rank of FVs for eating, ranking patterns showed a preference for avoiding TGVs for both sowing and eating, with two exceptions at the community level (Tab. 9). First, in La Palma, Cuba Pro FV and Pro TGV for sowing and Pro FV for eating patterns were also common. Second, in La Máquina, Guatemala a significant majority favored transgenic varieties for sowing, while avoiding them for eating. Again, La Máquina's strong

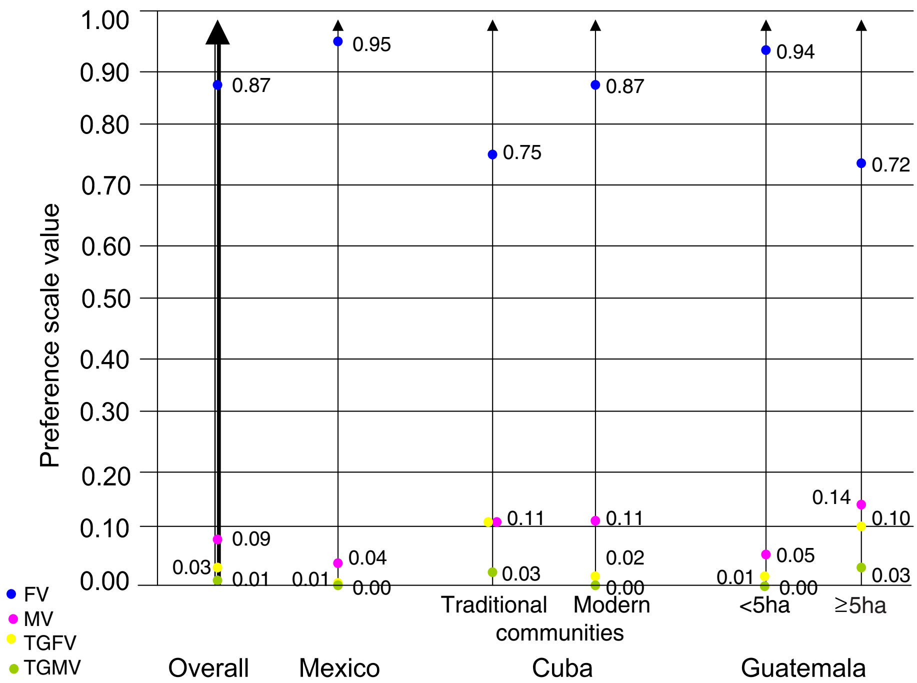

Figure 2. Farmer ranking preference scales: eating × country-specific covariates.

commercial orientation may account for its distinct perspective.

The heterogeneity of farmer evaluations of TGVs reported here, similar to those of consumers worldwide (Gaskell et al., 2003; Hallman et al., 2004), means that developing policies for TGVs will be complex, and extending assumptions to large populations such as small farmers in Mesoamerica is not valid. The ranking results provide quantitative estimates of that diversity in terms of specific questions.

These findings suggest that although it may be difficult to include farmer evaluation of potential harm from TGVs in the RMP, it is essential to do so in order to include variables important to farmers and critical to TBAS functioning. The assumption of TGV opponents that the process of transgenesis is culturally unacceptable to all TBAS farmers (Gonzalez, 2005) is not supported by our results, neither is the assumption of TGV proponents that farmer acceptance of transgenesis is tantamount to acceptance of TGVs (as some proponents have interpreted our findings). The possible consequences of using a hypothetical *Bt* maize were unacceptable to a significantly larger majority (86.3%) than found transgenesis *per se* acceptable (66.2%, $\chi^2 = 7.663$, $P = 0.0056$), and most farmers preferred non-transgenic varieties, especially for eating, but also for planting. Process (transgenesis), product (maize varieties), and consequences (seed procurement systems and prices, yield potential and variation) need to be clearly distinguished in research with farmers. There are farmers for whom transgenesis *per se* is unacceptable regardless of its known or presumed outcome. Others are open to the technology but their evaluations of it depend on their circumstances, and on the consequences, as is common in industrial systems. Consequences acceptable in industrial agriculture, such as yields responsive to improved environmental conditions and reliance on the formal crop improvement and seed multiplication and distribution systems, are perceived differently by TBAS farmers than farmers in industrial systems. As a result such consequences may be overlooked in RMPs or presumed to be irrelevant because TBAS are irrelevant. Clearly, care must be taken in interpreting farmers' evaluation of harm and its implication for risk management and policy, and assumptions of both genetic engineering opponents and proponents should not be substituted for farmers' own opinions and experience. If the principle of broad participation in the RMP by those affected by TGVs is to be followed, involving TBAS farmers in a meaningful way is critical.

There are a small but growing number of studies of TGV impact in the Third World. Many of these are about commercial production of *Bt* cotton (*e.g.*, in China, Huang et al., 2003; South Africa, Thirtle et al., 2003; Mexico, Traxler and Godoy-Avila, 2004). Important benefits have been documented including decreased pesticide use, and production costs associated with this. One study in China found approximately three quarters of farmers believed it safe to use *Bt* cotton products (Yang et al., 2005), though details of methodology are not given. Fewer studies are available about food crops. *Bt* rice in China was reported to provide results similar to cotton as well as higher yields and short term health benefits presumed due to farmers' decreased pesticide exposure (Huang et al., 2005). An *ex ante* study of transgenic maize for Kenya (de Groote et al., 2005), concluded it would be beneficial. The findings of these studies are important data points in local assessments of TGV impacts on TBAS. However, other factors including farmer knowledge and values regarding technological change, resistance evolution management, consolidation of seed systems, long term effects on genetic diversity must also be included in these assessments, as should a cost benefit analysis including alternative technologies (*e.g.*, mixed plantings to control rice pests in China, Zhu et al., 2000).

Our results suggest that the RMP for transgenic varieties in TBAS needs to be specifically tailored to this situation in general, and to each distinct community — results from the application of RMPs used in the US or other industrial countries are not appropriate or scientifically valid. It is important to do this as soon as possible because transgenic seed and grain is rapidly entering TBAS systems with a critical role in future food production and social support (Nadal, 2000; Narayanan and Gulati, 2002). Farmers' responses also suggest the need to investigate whether the same institutions that have produced technologies not adopted by TBAS farmers in the past are developing the most appropriate crop varieties for those farmers now. Working directly with farmers to understand the potential consequences of new technologies for TBAS can help insure that investment in agricultural research will be wisely made so as to improve, not compromise those critical food production systems and achieve the best possible outcome for TBAS farmers and communities.

MATERIALS AND METHODS

Study sites and sampling

In each of the countries (Cuba, Guatemala, Mexico) two contrasting TBAS were chosen — one more traditional (identified by "T" in the tables), and one relatively more modern (identified by "M" in tables) with greater market integration and use of modern agricultural technologies. Community choice was based on the authors' knowledge and available resources. The units sampled differed between countries based on the structure or history of agriculture — communities in Mexico, local agricultural credit cooperatives in Cuba, and agricultural production zones in one location in Guatemala. All interviews were in Spanish or the local indigenous language, as noted below.

Cuba

Most farm households in Cuba are members of agricultural cooperatives (farmer organizations acquiring financial or other inputs as a group from the government): credit cooperatives acquire credit that is then distributed among the individual family farms that are members, production cooperatives obtain government support that this used on collective production units worked by multiple households. We interviewed almost all households in (1) four credit cooperatives in the more traditional zones of La Jocuma and El Tejar (21 of 21 farming households) and La Lima (35 of 37 farming households), associated with the town of La Palma, El Pinar Province, comprising 97% of households in the three zones who are credit cooperative members, and (2) all households in the two credit cooperatives of the more modern agricultural community of Mayorquín in the commercial maize production zone of Holguin Province. Mayorquín lies within the region of Velasco that has recently become a focus of research due to its unusually high rates of cancer and congenital diseases (J. Anderes and O. Chaveco, personal communication, August 2005, La Habana, Cuba). The Cuban samples differed from those in Guatemala and Mexico because they included all or almost all members of the particular local sampling units (credit cooperatives).

Guatemala

Interviews were conducted in (1) the more traditional community of El Rejón, Department of Sacatepequez in the central altiplano and (2) the more modern community of La Máquina, Department of Suchitepequez in the commercial maize area on the Pacific coast. Residents of El Rejón are indigenous Kachikel farmers increasingly involved in commercial horticultural production for export while continuing to grow maize for staple household consumption. Farmers in La Máquina are Mestizo, primarily placed there as part of land reform policies in the 1960s, where they produce 2.3% of the country's commercial maize. A complete map of each community was obtained or drawn by researchers and local residents, and houses selected at specified intervals along the entire length of paths and streets throughout the community. In El Rejón local field assistants provided translation into Kakqchiquel when necessary.

Mexico

Interviews were conducted in the state of Oaxaca in (1) the more traditional community of Santa Inez Yatzeche in the Central Valleys of Oaxaca, and (2) the more modern agricultural community of Comitancillo in the Isthmus of Tehuantepec, where farmers are involved in commercial agriculture (sesame and some maize). Sampling method was the same as for Guatemala. In Comitancillo where not all households farm, we limited the sample to those listed as participants in the national agricultural support program PROCAMPO (defined as receiving cash payments of approx \$100.ha^{-1}.year^{-1} in 2004). While both communities are indigenous Zapotec, Comitancillo contrasts with Santa Inez Yatzeche in being more commercially oriented and having contact with modern agriculture *via* the local agricultural technical college there and the presence of agricultural scientists from a national agricultural university who have experimental plots there. In both locations field assistants fluent in the local Zapotec dialect provided translation when necessary.

The risk management process

Due to the lack of data on TGVs in TBAS, (NRC 1996:156–158), we identified *potential* for exposure and farmers' evaluations of harm, and not numerical probabilities.

We used informal event trees to qualitatively illustrate processes and potential harm, as a basis for scenarios (Cleveland and Soleri, 2005). Event tree analysis has been used extensively for industrial technologies to estimate the probability of risk, but rarely in agriculture, although the NRC has recommended more research to evaluate its usefulness for TGVs (NRC, 2002: 96–98).

Interview questions

Formal interviews were conducted between October 2003 and December 2004. Farmers were asked about: (a) characteristics of farms, farming practices and household members using a list of standard questions, (b) scenarios of hypothetical but plausible situations that used visual aides to assist researchers and farmers visualize and discuss concepts in terms familiar and relevant to their own experiences (Soleri and Cleveland, 2005), and (c) ranking of four different maize varieties for sowing and eating. Answers produced continuous (a) and categorical (a, b, c) data. Scenarios for eliciting farmer evaluations of potential harm were as follows.

Cultural harm due to transgenesis per se

Farmers were presented with the following description: "In the US and Europe there is a new kind of maize created with laboratory techniques that place properties, very very small bits invisible to the human eye, from other plants and animals into maize, though it looks like any other maize plant. With these methods plants can acquire properties they would not otherwise have. This kind of maize is being planted and eaten in those countries and there are no known health or environmental problems, though we do not know what the consequences will be over the long term. What do you think of this act of putting properties of other plants and animals into maize: good, bad (unacceptable), does not matter, depends on the consequences?"

Yield vs. yield stability in response to V_E

The scenario was presented to farmers using bags of grain to represent yields and stones of different sizes representing amounts of rainfall as visual aides. It described two maize varieties that differ only in their yields under different amounts of precipitation, and included a specific distribution of rainfall over a ten year period (Fig. 3). Rainfall variation is limiting and familiar to the farmers we spoke with; for example it has been estimated that maize farmers in the Central Valleys of Oaxaca experience yield failure one year in four due to drought (Dilley, 1997).

Yield vs. yield stability in a hypothetical TGV

This scenario presented farmers with two varieties differing only in their long-term yield, seed source and cost. These were described as varieties of maize similar in all ways except those depicted in the scenario, and were never identified as transgenic or not (Fig. 4). Farmers were asked to choose the variety best for them. Varieties $Z_{1\text{-}n}$ represent a series of hypothetical varieties with properties of hypothetical, locally appropriate *Bt* maize varieties, and much higher yields than variety X the first years planted, due to lower pest damage. However, as a result of the evolution of pest resistance to the *Bt* transgene, yields fall, and to regain high yields one Z variety has to be periodically

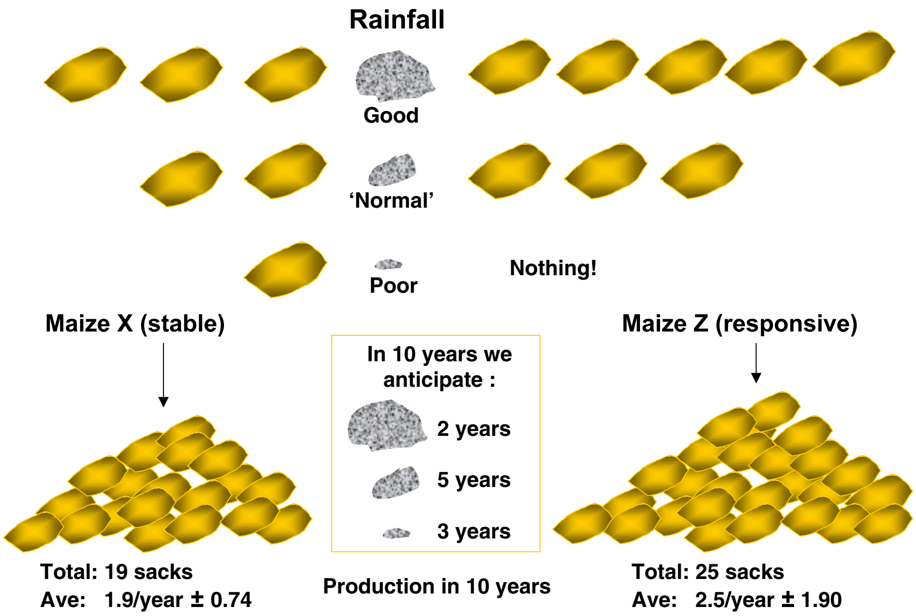

Figure 3. Yield *vs*. yield stability in response to V_E scenario presented to maize farmers. Rocks of different sizes represent different annual rainfall, sacks of maize grain represent yield response of a variety to that rainfall.

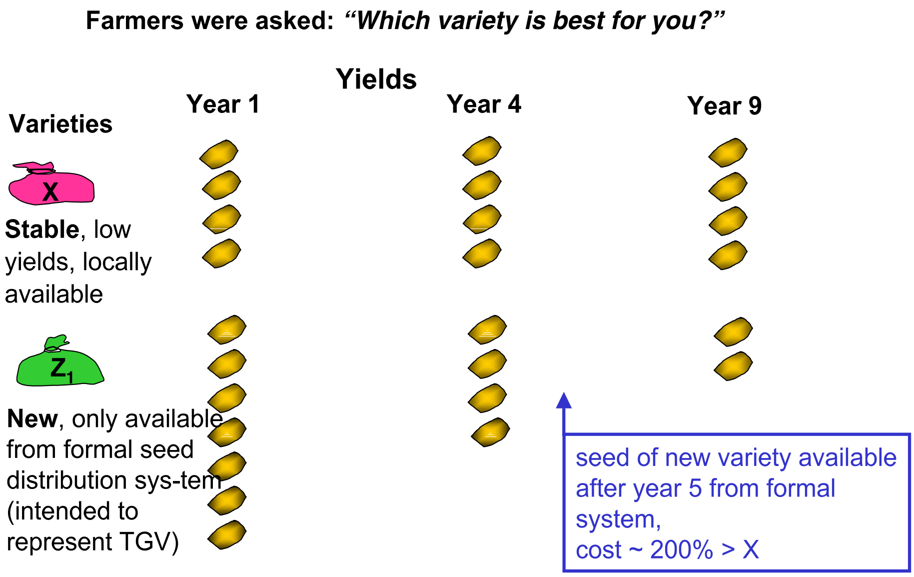

Figure 4. Yield *vs*. yield stability in a hypothetical TGV. Scenario for farmers' evaluation based on possible consequences of evolution of pest resistance to a hypothetical *Bt* transgene in maize.

replaced by a new one purchased from the formal seed distribution system (until then seed saving is possible). In contrast, variety X has low but stable yields, and farmers obtain seed from the informal distribution system. Seed for Z are twice as expensive as those for X. Scenario details were based on simulations of potential resistance evolution under different environmental parameters (Storer, 2003), reviews of resistance evolution (Gould, 1998) and local conditions (seed sources, locations, cost) known to the authors.

Figure 5. Maize ranking exercise presented to farmers.

Ranking exercises

We presented farmers with the ranking exercise shown in Figure 5, again using bags of maize grain to aid our discussion. Our assumption was that no deleterious linkage effects or other consequences for endogenous gene expression would occur due to the transgene. Farmers were asked to conduct their ranking based on their knowledge, including their experience with, and values and beliefs about, FVs, MVs and the explanation of transgenesis and TGVs given in the previous scenarios. As seen earlier (Tab. 2), most were unfamiliar with transgenic maize and we described two examples of TGVs to them to help conceptualize what they might be. First, *Bt* maize with "properties taken from a small organism that lives in the soil that has the capacity to resist certain caterpillars, giving that capacity to the maize." Second, strawberries with the "ability to tolerate cold weather due to properties taken from fish that live in cold water." Although the latter is an "urban legend" constructed around research that has been fruitless (Kenward et al., 1999), it has been used by both proponents and opponents of TGVs to represent the wondrous or ominous potential of crop biotechnology (www.geo-pie.cornell.edu/media/fishberries.html#f4).
We explained that *Bt* maize is now being grown and consumed in the US, Europe and elsewhere. Farmers were asked to compare and rank the four maize varieties for sowing and eating separately. Rankings of individual maize varieties were analyzed as were patterns of rank choices. The choices available to farmers in this ranking exercise can produce 12 different patterns of preferences for the first two positions (best, 2nd best) in any order. Four of these patterns are created by choosing only one *type* of maize: Pro FV = FV and TGFV, Pro MV = MV and TGMV, Pro TGV = TGFV and TGMV, Avoid TGV = FV and MV.

Data analysis

We use descriptive statistics to characterize farms, households and their practices; χ^2 goodness of fit and likelihood tests of frequency distributions to analyze responses to scenarios and other categorical data; t-tests for comparison of means, and an extended Bradley-Terry (B-T) model (written in R) of paired-comparisons that incorporates subject-specific covariates (Dittrich et al., 1998) for analysis of ranking data. The extended B-T model was implemented using SAS to configure the data and the R-language function for generalized linear models to fit the models. SAS version 8.02 (SAS Institute, 2001) was used for all data analyses.

In the B-T analysis, the model allows for the extraction of rankings of objects on a preference scale. The baseline model is defined as:

$$\Pi_{(jk)j} = \frac{\pi j}{\pi_j + \pi_k} \quad (1)$$

where $\Pi_{(jk)j}$ is the probability of picking j in the comparison of j and k; the π*'s* are the preference scale parameters. The extended B-T model allows for a more complete assessment of the ranking data through inclusion of subject-specific covariates. We tested the hypothesis that characteristics such as farm size, community type, etc., might affect either the degree or order of preference among maize varieties. The extension is made possible by recognizing that the B-T can be reformulated as a log-linear model, as shown by Fienberg and Larntz (Fienberg and Larntz, 1976). The extended B-T model uses three equations for each paired comparison,

$$\ln(m_{(jk)j|l}) = \mu_{(jk)jl} + \lambda_j^O - \lambda_k^O + \lambda_l^S + \lambda_{jl}^{OS} - \lambda_{kl}^{OS} \quad (2)$$

$$\ln(m_{(jk)k|l}) = \mu_{(jk)jl} - \lambda_j^O + \lambda_k^O + \lambda_l^S - \lambda_{jl}^{OS} + \lambda_{kl}^{OS} \quad (3)$$

$$\ln(m_{(jk)O|l}) = \mu_{(jk)jl} + \lambda_l^S + \delta \quad (4)$$

The first two equations specify j preferred to k and k preferred to j respectively, where m is the expected number of preferences. The third equation allows for the inclusion of tied comparisons with the parameter *delta* indicating the odds of a decision when the objects are evenly matched. The λ^O are the traditional B-T model parameters and the μ are nuisance parameters that are included to constrain marginals. Lastly, the λ^S, a subject covariate main effect, and λ^{OS}, an object-subject interaction, allow for the expected number of preferences to be conditioned on the levels of a covariate. If the object or object-subject interaction parameters are insignificant then the model collapses back to the basic B-T model. However, if the parameters are significantly different from zero the model can be used to infer more complex structure to preferences. Since the model is an instance of a log-linear model it can be fitted and evaluated using standard software for generalized linear models. We used standard methods of evaluation to assess the model fit (reduction in deviance, change in Akaike Information Criteria [AIC]) as well as significance of individual parameters. In each case we started with a full model including the δ parameter to assess the impact of ties. In most of the models there were few tied preferences and δ parameters were insignificant.

ACKNOWLEDGEMENTS

We thank the farmers who have participated in this research and taught us much; our colleagues and institutions (UCSB, INIFAP, ICTA, INCA) for support, including fieldwork assistance from R González, C Permuy, O Chaveco (Cuba), J Martinez, J Espital, D Veliz, M Poma (Guatemala); three anonymous reviewers for EBR; and the Wallace Genetic Foundation, the US National Science Foundation (SES-9977996, DEB-0409984), and the UCSB Faculty Senate for funding.

Received September 9, 2005; accepted November 23, 2005.

REFERENCES

Alvarez-Buylla E (2003) Ecological and biological aspects of the impacts of transgenic maize, including agro-biodiversity, Prepared for the Secretariat of the Commission for Environmental Cooperation of North America, as part of the Article 13 initiative on Maize and Biodiversity: the Effects of Transgenic Maize in Mexico. Published on line at www.cec.org

Alvarez-Morales A (2002) Transgenes in maize landraces in Oaxaca: official report on the extent and implications. http://www.worldbiosafety.net/

Andow DA, Daniell H, Gepts P, Lamkey KR, Nafziger E, Strayer D (2004) A growing concern: Protecting the food supply in an era of pharmaceutical and industrial crops. Union of Concerned Scientists, Cambridge, MA. Union of Concerned Scientists, Washington, DC

Aquino P, Carrión F, Calvo R, Flores D (2001) Selected maize statistics. In Pingali PL, ed., CIMMYT 1999–2000 World maize facts and trends. Meeting world maize needs: technological opportunities and priorities for the public sector. CIMMYT, DF, Mexico, pp 45–57

Aragón Cuevas F, Soleri D, Cleveland DA (n.d.) Farmers' practices, knowledge and values regarding maize improvement and transgenes in four communities in Oaxaca, Mexico

Brown AHD (1999) The genetic structure of crop landraces and the challenge to conserve them *in situ* on farms. In Brush SB, ed, Genes in the field: on-farm conservation of crop diversity. Lewis Publishers; IPGRI; IDRC, Boca Raton, Florida; Rome; Ottawa, pp 29–48

Burgess JA, Walsh AJ (1998) Is genetic engineering wrong, *per se*? *J. Value Inquiry* **32**: 393–406

CEC (2004) Maize and biodiversity: the effects of transgenic maize in Mexico. Key findings and recommendations. Secretariat article 13 report. Montreal: CEC. 2004. 2004 Nov 10. http://www.cec.org/files/PDF//Maize-and-Biodiversity_en.pdf

Ceccarelli S (1997) Adaptation to low/high input cultivation. In Tigerstedt PMA, ed, Adaptation and plant breeding. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 225–236

Ceccarelli S, Erskine W, Hamblin J, Grando S (1994) Genotype by environment interaction and international breeding programmes. *Exp. Agric.* **30**: 177–187

CGIAR (2005) CGIAR & agricultural biotechnology: CGIAR. 2005. March 7. http://www.cgiar.org/impact/agribiotech.html

Chilcutt CF, Tabashnik BE (2004) Contamination of refuges by *Bacillus thuringiensis* toxin genes from transgenic maize. *Proc. Natl. Acad. Sci. USA* **101**: 7526–7529

Cleveland DA (2001) Is plant breeding science objective truth or social construction? The case of yield stability. *Agric. Human Values* **18**: 251–270

Cleveland DA, Soleri D, eds (2002) Farmers, scientists and plant breeding: integrating knowledge and practice. CABI Publishing, Oxon, UK

Cleveland DA, Soleri D (2005) Rethinking the risk management process for GE crops in Third World agriculture. *Ecol. Society* **10** (1): Article 9. [online] http://www.ecologyandsociety.org/vol10/iss1/art9/

Daniell H (2002) Molecular strategies for gene containment in transgenic crops. *Nat. Biotechnol.* **20**: 581–586

De Groote H, Mugo S, Bergvinson D, Odhiambo B (2005) Assessing the benefits and risks of GE crops: evidence from the Insect Resistant Maize for Africa Project. *ISB News* February 2005: 7–9

Dilley M (1997) Climatic factors affecting annual maize yields in the valley of Oaxaca, Mexico. *Int. J. Climatol.* **17**: 1549–1557

Dittrich R, Hatzinger R, Katzenbeisser W (1998) Modelling the effect of subject-specific covariates in paired comparison studies with an application to university rankings. *J. R. Stat. Soc. Ser. C-Appl. Stat. soc.* **47**: 511–525

Doebley J (2004) The genetics of maize evolution. *Annu. Rev. Genet.* **38**: 37–59

Eastham K, Sweet J (2002) Genetically modified organisms (GMOs): the significance of gene flow through pollen transfer. European Environment Agency, Copenhagen, Denmark

Ellis F (1993) Peasant economics: farm households and agrarian development. Cambridge University Press, Cambridge, UK

Ellstrand NC (2003) Current knowledge of gene flow in plants: implications for transgene flow. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* **358**: 1163–1170

Ellstrand NC (2003a) Dangerous liaisons? When cultivated plants mate with their wild relatives. Johns Hopkins University Press, Baltimore

Ellstrand NC (2003b) Going to "great lengths" to prevent the escape of genes that produce specialty chemicals. *Plant Physiol.* **132**: 1770–1774

EPA (1998) The Environmental Protection Agency's White Paper on *Bt* Plant-pesticide Resistance Management, EPA White Papers. EPA, Washington, DC, pp 78

Evans LT (1993) Crop evolution, adaptation and yield. Cambridge University Press., Cambridge, UK

Evans LT (1998) Feeding the ten billion: Plants and population growth. Cambridge University Press, Cambridge, UK

Falkenmark M (1994) Landscape as life-support provider: water-related limitations. In Graham-Smith F, ed, Population, the complex reality. The Royal Society, London, pp 103–116

FAO (2004) Agricultural biotechnology: meeting the needs of the poor? The state of food and agriculture. Food and Agriculture Organization, United Nations, Rome, Italy

FAOSTAT Data (2005) *Agricultural Data*. 2005. 4 July 2005. http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0&subset=agriculture

Fernandez-Cornejo J (2004) The seed industry in US agriculture. In USDA-ERS, ed, Agriculture Information Bulletin. USDA-ERS, pp 81

Fienberg SE, Larntz K (1976) Log linear representation for paired and multiple comparisons models. *Biometrika* **63**: 245–254

Fitt GP, Andow DA, Carriére Y, Moar WJ, Schuler TH, Omoto C, Kanya J, Okech MA, Arama P, Maniania NK (2004) Resistance risks and management associated with *Bt* maize in Kenya. In Hilbeck A, Andow DA, eds, Environmental risk assessment of genetically modified organisms: Volume 1. A case study of Bt maize in Kenya. CAB International, Oxfordshire, UK, pp 209–250

Frankel OH, Brown AHD, Burdon JJ (1995) The conservation of plant biodiversity. Cambridge University Press, Cambridge, UK

Frewer L (2003) Societal issues and public attitudes towards genetically modified foods. *Trends Food Sci. Technol.* **14**: 319–332

Gaskell G, Allum N, Stares S (2003) Europeans and Biotechnology in 2002. A report to the EC Directorate General for Research from the project 'Life Sciences in European Society' QLG7-CT-1999-00286. Public Opinion Analysis Sector, European Commission, http://europa.eu.int/comm/public{Iopinion/archives/ebbb/ebs}177{Ien.pdf, Brussels, Belgium}}

Goklany IM (2002) From precautionary principle to risk-risk analysis. *Nat. Biotechnol.* **20**: 1075

Gonzalez A (2005) Territory, autonomy and defending maize. *Seedling* (January): 14–17

Goodman MM (2004) Plant breeding requirements for applied molecular biology. *Crop Sci.* **44**: 1913–1914

Gould F (1998) Sustainability of transgenic insecticidal cultivars: integrating pest genetics and ecology. *Annu. Rev. Entomol.* **43**: 701–726

Gould F, Cohen MB (2000) Sustainable use of genetically modified crops in developing countries. In Persley G, Lantin M, eds, Agricultural biotechnology and the poor: an international conference. CGIAR (Consultative Group on International Agricultural Research), Washington, DC, pp 139–146

Hallman WK, Hebden WC, Cuite CL, Aquino HL, Lang JT (2004) Americans and GM food: Knowledge, opinion and interest in 2004. Food Policy Institute, Cook College, Rutgers – The State University of New Jersey, New Brunswick, New Jersey

Hardaker JB, Huirne RBM, Anderson JR (1997) Coping with risk in agriculture. CAB International, Wallingford, Oxon, UK

Heisey PW, Edmeades GO (1999) Part 1. Maize production in drought-stressed environments: technical options and research resource allocation. In CIMMYT, ed, World maize facts and trends 1997/98. CIMMYT, Mexico, DF, pp 1–36

Hernández Xolocotzi E (1985) Maize and man in the greater southwest. *Econ. Bot.* **39**: 416–430

Hilbeck A, Andow DA, eds (2004) A case study of Bt maize in Kenya. CABI, Wallingford, Osfordshire, UK

Huang J, Hu R, Pray C, Qiao F, Rozelle S (2003) Biotechnology as an alternative to chemical pesticides: a case study of Bt cotton in China. *Agric. Econ.* **29**: 55–67

Huang JK, Hu RF, Rozelle S, Pray C (2005) Insect-resistant GM rice in farmers' fields: Assessing productivity and health effects in China. *Science* **308**: 688–690

INEGI (1996) Anuario Estadístico del Estado de Oaxaca, Edición 1996. INEGI, Aguascalientes, Aguascalientes, Mexico

INEGI (2001) Sistema para la consulta del annuario estadístico. INEGI, Aguascalientes, Aguascalientes, Mexico

INEGI (2005) Indicadores del XII censo general de población y vivienda 2000. Mexico. 2005. 2 August 2005. http://www.inegi.gob.mx/est/default.asp?c=5171

Instituto Nacional de Economia (2004) IV Censo Nacional Agropecuario 2003. INE, Guatemala

James C (2004) Preview: global status of commercialized biotech/GM crops: 2004. Ithaca, NY: ISAAA. http://www.isaaa.org/kc/CBTNews/press_release/briefs32/ESummary/Executive%20Summary%20(English).pdf

Kenward K, Brandle J, McPherson J, Davies P (1999) Type II fish antifreeze protein accumulation in transgenic tobacco does not confer frost resistance. *Transgenic Res.* **8**: 105–117

Klinger T (2002) Variability and uncertainty in crop-to-wild hybridization. In Letourneau DK, Elpern Burrows B, eds, Genetically engineered organisms: assessing environmental and human health effects. CRC Press, Boca Raton, Florida, pp 1–15

Louette D, Charrier A, Berthaud J (1997) In situ conservation of maize in Mexico: genetic diversity and maize seed management in a traditional community. *Econ. Bot.* **51**: 20–38

Louette D, Smale M (2000) Farmers' seed selection practices and maize variety characteristics in a traditional Mexican community. *Euphytica* **113**: 25–41

Luna VS, Figueroa J, Baltazar MB, Gomez LR, Townsend R, Shoper JB (2001) Maize pollen longevity and distance isolation requirements for effective pollen control. *Crop Sci.* **41**: 1551–1557

Ma BL, Subedi KD, Reid LM (2004) Extent of cross-fertilization in maize by pollen from neighboring transgenic hybrids. *Crop Sci.* **44**: 1273–1282

Matsuoka Y, Vigouroux Y, Goodman MM, Sanchez GJ, Buckler E, Doebley J (2002) A single domestication for maize shown by multilocus microsatellite genotyping. *Proc. Natl. Acad. Sci. USA* **99**: 6080–6084

Messeguer J (2003) Gene flow assessment in transgenic plants. *Plant Cell Tissue Organ Cult.* **73**: 201–212

Millennium Project (2005) Halving hunger: it can be done. Earthscan, London

Monsanto Company (2004) Growing options. Monsanto 2004 pledge report. St Louis, Missouri: Monstanto Company. 2004. November 9. http://www.monsanto.com/monsanto/content/media/pubs/2004/pledgereport.pdf

Mora JE (2005) *Central America: UN agency accused of distributing GM foods*: Inter Press Service News Agency. 2005. June 23. http://ipsnews.net/new_nota.asp?idnews=27498

Morris ML (1998) Maize seed industries in developing countries. Lynne Rienner, Boulder, Colorado

Murphy K, Lammer D, Lyon S, Carter B, Jones SS (2005) Breeding for organic and low-input farming systems: An evolutionary-participatory breeding method for inbred cereal grains. *Renew. Agric. Food Syst.* **20**: 48–55

Nadal A (2000) The environmental and social impacts of economic liberalization on corn production in Mexico. World Wide Fund for Nature, and Oxfam GB, Gland, Switzerland, and Oxford, UK

Narayanan S, Gulati A (2002) Globalization and the smallholders: a review of issues, approaches, and implications. International Food Policy Research Institute (IFPRI), Washington, DC

Nelson KC, Kibata G, Muhammad L, Okuro JO, Muyekho F, Odinho M, Ely A, Waquil JM (2004) Problem formulation and options assessment (PFOA) for genetically modified organisms: The Kenya case study. In Hilbeck A, Andow DA, eds, Environmental risk assessment of genetically modified organisms, Volume 1: A case study of Bt maize in Kenya. CAB International, Walingford, UK, pp 57–82

NRC (1996) Understanding risk: informing decisions in a democratic society. National Academy Press, Washington, DC

NRC (2002) Environmental effects of transgenic plants: the scope and adequacy of regulation. National Academy Press, Washington, DC

NRC (2004) Biological confinement of genetically engineered organisms, Washington, DC

Ortiz-García S, Ezcurra E, Schoel B, Acevedo F, Soberón J, Snow AA (2005) Absence of detectable transgenes in local landraces of maize in Oaxaca, Mexico (2003-2004). *Proc. Natl. Acad. Sci. USA* **102**: 12338–12343

Pressoir G, Berthaud J (2004) Patterns of population structure in maize landraces from the Central Valleys of Oaxaca in Mexico. *Heredity* **92**: 88–94

Quist D, Chapela IH (2001) Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico. *Nature* **414**: 541–543

SAGARPA (2004) Producción agrícola, año 2003, Servicio de información y estadística agroalimentaria y pesquera (SIAP). Mexico: SAGARPA. 2005. 2 August 2005. http://www.sagarpa.gob.mx

SAS Institute (2001) SAS System for Windows. SAS Institute Inc., Cary, North Carolina

Simmonds NW, Smartt J (1999) Principles of crop improvement. Blackwell Science Ltd., Oxford, UK

Snow AA, Andow DA, Gepts P, Hallerman EM, Power A, Tiedje JM, Wolfenbarger LL (2005) Genetically engineered organisms and the environment: Current status and recommendations. *Ecol. Appl.* **15**: 377–404

Soleri D, Cleveland DA (2005) Scenarios as a tool for eliciting and understanding farmers' biological knowledge. *Field Methods* **17**: 283–301

Soleri D, Cleveland DA, Smith SE, Ceccarelli S, Grando S, Rana RB, Rijal D, Ríos Labrada H (2002) Understanding farmers' knowledge as the basis for collaboration with plant breeders: methodological development and examples from ongoing research in Mexico, Syria, Cuba, and Nepal. In Cleveland DA, Soleri D, eds, Farmers, scientists and plant breeding: integrating knowledge and practice. CAB International, Wallingford, Oxon, UK, pp 19–60

Soleri D, Smith SE, Cleveland DA (2000) Evaluating the potential for farmer and plant breeder collaboration: a case study of farmer maize selection in Oaxaca, Mexico. *Euphytica* **116**: 41–57

Storer NP (2003) Sensitivity analysis of a spatially-explicit stochastic simulation model of the evolution of resitance in *Helicoverpa zea* (Lepidoptera: Noctuidae) to Bt transgenic corn and cotton. *J. Econ. Entomol.* **96**: 173–187

Thirtle C, Beyers L, Ismael Y (2003) Can GM-Technologies Help the Poor? The Impact of Bt Cotton in Makhathini Flats, KwaZulu-Natal. *World Develop.* **31**: 717–732

Traxler G, Godoy-Avila S (2004) Transgenic cotton in Mexico. *AgBioForum* **7**: 57–62

USDA FAS (2005) FAS Online US Trade Internet System

USDA NASS (2004) Crop Production-Prospective Planting-Supplement. 2004. nov 9. http://www.nass.usda.gov/census/census02/volume1/us/st99_1_001_001.pdf

Walker TS (1989) Yield and household income variability in India's semi-arid tropics. In Anderson JR, Hazell PBR, eds, Variability in Grain Yields: Implications for agricultural research and policy in developing countries. Johns Hopkins University Press, Baltimore, Maryland, pp 309–319

Yang PY, Iles M, Yan S, Jolliffe F (2005) Farmers' knowledge, perceptions and practices in transgenic Bt cotton in small producer systems in Northern China. *Crop Prot.* **24**: 229–239

Zeven AC (1998) Landraces: a review of definitions and classifications. *Euphytica* **104**: 127–139

Zhong G-Y (2001) Genetic issues and pitfalls in transgenic breeding. *Euphytica* **118**: 137–144

Zhu YY, Chen HR, Fan JH, Wang YY, Li Y, Chen JB, Fan JX, Yang SS, Hu LP, Leung H, Mew TW, Teng PS, Wang ZH, Mundt CC (2000) Genetic diversity and disease control in rice. *Nature* **406**: 718–722